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Service paper

AN APPROACH TO THE TEACHING OF

MECHANICS AND ELECTRICITY

Submitted by

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    *This constitutes a sampling of an auxiliary text for
      physics students.

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physics students.

RANGE OF INVESTIGATION

Purpose.

The best methods for learning physics have been analyzed less frequently than for learning English, social studies and mathematics. This paper is concerned with physics as taught in the junior and senior years of preparatory schools, and specifically with the portions of the subject included in the mechanics of solid bodies and in direct current electricity. Within these areas it is intended to present:

--an approach to a scheme of activities from which the learner can inductively organize the subject for himself.

--an approach to a line of reasoning from observation of facts through laws to theories.

--suggestions for improved ways of thinking about important concepts.

--descriptions avoiding complexity in the use of physical units.

--explanations avoiding statements which are incorrect, or which can be misinterpreted.

In the first portion--Range of Investigation--this paper will discuss from the standpoint of the teacher the need for improved presentation of mechanics and electricity at the level of grade XI or XII, and the pitfalls which lie in the way of obtaining it. The latter portion is written for the young learner as a replacement for limited parts of the usual textbooks.

The need is set forth in the Forty-sixth Yearbook[1]

"The picture we get is of a subject, physics, gone stale through adherence to a set and largely nonfunctional pattern

[1] National Society for the Study of Education. Science Education in American Schools, Forty-sixth Yearbook, 1947, Part I, page 209. Chicago: The University of Chicago Press.

of organization. A thorough overhauling both as to the content and organization seems in order."

Approaching the science curriculum from the point of view of learning units in physics, Hoff says,[1]

"It is true, however, that up to the present time this form of organization has been more prevalent in the more elementary subjects in the field of science, such as elementary science and biology. This does not mean, however, that the unit plan of organization is not just as applicable in chemistry and physics. The reason for the lack of development in the more advanced sciences is due apparently to lack of effort in the preparation of these materials. In due time, instructional materials organized on this plan will be as common as in the other areas before mentioned."

After reviewing the remarkable, though not necessarily desirable, uniformity of topics in seven textbooks in secondary school physics, Billett says,[2]

"It would be a comparatively easy task for a qualified teacher to translate them (the topics) into worth-while learning products (concepts, skills, ideals, attitudes, and appreciations) and to select supplementary subject matter which when psychologically organized along with the textual materials, would be likely to lead out to the desired learning products by the experiential route. But it is a task which most local physics teachers have yet to do...The facts briefly surveyed justify the generalization that desirable departures from stereotyped, traditional procedures in the organization and modes of presentation of secondary-school science courses have been frequent in general science courses, rare in biology, very exceptional in chemistry, and almost unique in physics."

Reputation of Physics.

Billett suggests, immediately following this quotation, that there may be some relation between lack of psychological organization and low enrollment in physics courses. It is quite easy to present a case for the growth in importance of studying physics in high school, and equally easy to pre-

[1] Arthur G. Hoff. Secondary School Science Teaching, page 76. Philadelphia: The Blakiston Company, 1947.

[2] Roy O. Billett. Fundamentals of Secondary School Teaching, page 267. Boston: Houghton Mifflin Company, 1940.

sent statistics of its decline in popularity as an elective subject. A
typical report[1] concerns the percentage of students in the College of
Education, Ohio State University, whose preparation had included one year
of physics or chemistry in high school.

Year	Physics	Chemistry
1913	80	33
1918	74	35
1923	50	51
1928	46	50
1933	37	67
1938	30	57
1943	19	54

Modern life has become notably dependent on such physical appliances as
radios, mechanical refrigerators and automobiles. Any family is indeed
to be pitied if there is not at least one member who, because of his
knowledge of physics, can make minor repairs or deal intelligently with a
service man. The recent war emphasized new devices and new designs based
on physics, and thousands of men well trained in physics are needed from a
military as well as an industrial standpoint. Yet, as the tabulation
shows, the percentage of pupils in high school who elected physics had
fallen from the beginning of the century to Pearl Harbor. This situation
presents a challenge to the teacher of physics, for it may be said to
have the reputation of being a difficult and obscure subject.

Nevertheless physics has been called the most typical of sciences,
in that the facts of inanimate nature are experimentally observed, laws
are developed to classify and coordinate the facts, and theories are ex-
pounded to explain the laws. From a relatively compact group of assump-

[1] Raymond D. Bennett. Trends in the Amount of Science Taken in High
School. School Review, 52, 406. September 1944.

tions, axioms and definitions, the explanation of all the facts is logically built up by reasoning. Yet as commonly taught at the high school level, such an approach is seldom even approximated. In too many text books, laws and theories are laid down for the learner to believe somewhat in the same way as an Arabian is expected to believe the tenets of Mohammed. It might be called descriptive indoctrination.

Common to many textbooks are features and characteristics of the exposition of elementary physics which, although they may not appear so, are needlessly complex or illogical. To cite instances, the definition 'electromotive force is the work done in moving a unit charge around a circuit' is meaningless to a student in the first year or two of electricity, and there is no analogy between this 'force' and a mechanical force. Drill in numerical conversion between metric and customary units requires, for the beginner, school time all out of proportion to its value in learning physical principles. Unless care is taken to reduce the number of nearly synonomous words, such as 'dielectric constant', 'specific inductive capacity' and 'capacitivity', the new vocabulary load may approach that expected of a young student taking a course in a foreign language.

Therefore, this paper is intended to examine the possibility of preparing an improved and modified approach. It may be that there are accepted principles of the psychology of learning which are violated in almost all usual approaches to the study of elementary physics. Some of these may be examined.

Some Principles of Learning Physics.

Among the principles of the psychology of learning which account for the difficulties of the grade XI or grade XII student is the principle of

maturation. Bailey[1] has found the concept of 'power' too difficult for most pupils in grade IX. Again take the broad underlying law of nature that some processes will go spontaneously in one direction, but cannot be made to go in the opposite. This involves the concept of entropy which has been found so baffling that teachers seldom if ever attempt it before grade XIV. Yet an application of this law is no more occult than a block of metal growing warm, as it slides down a rough incline, although the block fails to begin sliding back up the incline if the process be reversed by cooling it with ice.

The use of mathematical symbols and formulas is an example of what is meant by conditioning in the field of psychology of learning. Much physics has to be learned in the language of mathematics, for physics and mathematics have developed hand in hand for generations. The further the learner progresses the more hopeless it becomes to attempt physics without mathematical symbols. However, the alphabetical letters for many mechanical quantities are well standardized, as in the relation 's = v t' with 's' for length, 'v' for velocity and 't' for time. Hence the learner becomes conditioned to symbols. At first 's = v t' is a stimulus without a response. The spoken or unspoken words are added, and from them the idea evolves in the mind that a distance of 60 miles is covered by a train moving at 30 miles per hour for 2 hours. After the symbols 's = v t' have been encountered a sufficient number of times the intermediate step is eliminated, that of thinking words for symbols. Eventually conditioning reaches the

[1] Ralph G. Bailey. Difficulty Level of Certain Science Concepts, Science Education, 25, 84. February 1941.

stage where a more complicated formula like

$$f = \frac{1}{2\pi\sqrt{LC}}$$

produces as a direct response in the mind the idea of radio oscillations, just as reading the word 'apple' means all that it does about color, taste, odor and feel.

The learner also has to become conditioned to units of measure, as the 'foot-pound' for energy and the 'foot per second' for velocity. It is probably true that more conditioning of this sort is expected than a learner can actually assimilate in the time usually alloted to the study of mechanics.

Units of Measure.

Consider the vocabulary connected with units of measure. In mechanics a list includes the following.

mass	ounce	length	inch	force	pound
	pound		foot		poundal
	ton		mile		dyne
	slug		centimeter		newton
	gram		kilometer		gram
	kilogram				

energy	foot-pound	power	foot-pound per second
	joule		horsepower
	erg		joule per second

pressure	pound per square inch
	dyne per square centimeter
	atmosphere
	foot of water
	centimeter of mercury

It is apparent that, after extending this list with further units for volume, velocity, time and density, it is too long. Even the metric system is evolving, for example the newton has been introduced rather recently as a unit of force. Too often all such items are simply added on to what the student previously had to learn, without omitting something else for

compensation. Contrary to the impression created for the student, the metric system is not so interwoven into physics that his handicap must be compounded by using a double system of units, British and metric. The introduction of the metric system may be delayed until the student gets into some branches of physics easier than mechanics, except for some incidental use of centimeters and grams with laboratory apparatus. It is unfortunate that it is nearly impossible to buy equipment for simple laboratory work in mechanics in decimals of an inch and of a pound.

Simplification of Units.

To better emphasize how complex is the group of units employed in elementary physics, some suggestions for simplification may be made, though they are too fantastic for adoption.

If a choice must be made among the mile, the foot and the inch as units of length, it would be preferable to use the foot. Then for volumes only cubic feet would be used, and for pressures only pounds per square foot. Moreover it would be ideal to use a single word for the mechanical unit of energy, rather than the compound word 'foot-pound'. A word might be coined, such as one 'rumford' equals 1000 foot-pounds (equals 1.286 Btu).

Further, conceding the advantages of the metric system, and striving for the ultimate in the reduction of the number of units to the shortest possible set, a single unit of energy could be used throughout elementary physics, rather than the foot-pound, the Btu., the joule and the kilowatt-hour. The choice would probably be the kilojoule (equals o.95 Btu) for it would be worse to disturb the electrical units already in use, than to express mechanical forms of energy in kilojoules. In this connection it may be noted that at least as far back as 1924 the 'joule per centimeter'

has been proposed[1] as a unit of mechanical force. (One joule per centimeter equals 100 newtons equals 22.5 pounds of force).

Carrying such simplification to its logical conclusion, a new temperature degree might be defined such that one kilojoule would raise one kilogram of water one degree. The size of such a temperature unit relative to centigrade and fahrenheit is indicated in the diagram. If absolute zero were taken to be minus 1000 of the new degrees, then

$$0^\circ \text{ C} = 142.8 \text{ new degrees}$$
$$100^\circ \text{ C} = 561.1 \text{ new degrees}$$

Difficulties for the Student.

Units of measure form only part of the story of difficulties encountered. Now it is hardly feasible to begin an exposition of physics with the study of light, electricity or any other branch except mechanics, because logically the concepts of mechanics underlie those of the other branches. Yet the learner usually feels when he has got beyond mechanics that the study of heat, sound or light would have been an easier introduction. In an effort to list some features of learning mechanics which are difficult, the following may be mentioned.

The student has to deal with velocity and acceleration which Newton and Leibnitz could not handle until

[1] L. A. Hazeltine. Electrical Engineering, page 8. New York: The Macmillan Company, 1924.

they had invented the calculus, but he is not yet prepared to use the cal-
culus. He has to handle vectors and some of their characteristic mathematics,
although his previous algebraic training has been almost entirely with
scalars.

One of the particularly treacherous topics for the beginner in mechanics,
yet one which should be introduced before he reaches college, is the dis-
tinction between the pound of force and the pound of mass. For instance, if
asked to compute the necessary drawbar pull of a locomotive to accelerate
a train at one ft/sec/sec, he wonders why the mass of the train in pounds
has to be divided by 32. In this connection the use of the poundal of
force does not seem the best way out of the difficulty. Between the con-
cepts of force and of mass, the more elusive is force, hence it is better
to express mass in slugs but to leave force in the familiar unit, the
pound. One can show a student a slug of mass, and he can touch it. The
lift on an airplane is usually calculated using the density of air in slugs
per cubic foot. The slug could be defined as the absolute unit of mass,
equal to 32.174/o.45359 kilogram. Then at sea level in latitude 45 a force
of one pound would give a mass of one slug an acceleration of one ft/sec/sec.
Some theorists may object that heretofore when the slug has been used it has
been considered a gravitational unit. But already this topic has been
troublesome too long, and the change in the definition of the slug from
gravitational to absolute, without coining a new word, is an end which
justifies the means. Extreme variations in the gravitational pound of force
met in engineering design are negligible. Even on a rocket rising 200 miles
above sea level, the variation is only one percent.

Realistic Content.

Among various authorities who have dealt with the difficulties of

teaching physics, Noll expresses a common opinion when he says,[1]

> "The greatest need in the field of high school science teaching today is a reorganization of content to meet the needs and interests of present-day life."

Obviously this is not fulfilled if some items of content are not met outside the schoolroom. As a conspicuous instance, the 'unit pole' of magnetism may be mentioned. Historically, the position of the unit pole seems secure, but it is utterly hypothetical. Bennett[2] says,

> "Modern view indicates that all magnetic phenomena can be attributed to electrical considerations which make the magnetic pole an unnecessary concept."

Page says,[3]

> "Ampère's theory of magnetism enables us to dispense with the concept of a magnetic pole as a physical entity, and to ascribe all magnetic phenomena to the presence of electric currents."

The mathematics by which useful magnetic quantities have been historically derived from the unit pole are quite beyond grade XII. The proper rigorous method of treatment is along the lines used by Frank[4] where whatever slight physical reality there is for a unit pole is brought out, after a thorough development along other lines, but in a way that could never be presented to a beginner.

Numerical problems with the unit pole which occur in various textbooks are the baldest sort of mere substitutions in a formula, and devoid of

1/ Victor H. Noll. The Teaching of Science in Elementary and Secondary Schools, page 125. New York: Longmans, Green and Company, 1939.

2/ Clarence E. Bennett. An Outline of First Year College Physics, Third edition, pg. 93. New York: Barnes and Noble, 1939.

3/ Leigh Page. Introduction to Theoretical Physics, page 379. New York: D. Van Nostrand Company, 1929.

4/ Nathaniel H. Frank. Introduction to Electricity and Optics. New York: McGraw-Hill Book Company, 1940.

realism. For instance[1]/

>"At a distance of 5 centimeters in air a north magnetic
>pole of strength 5 will attract a south pole of strength 1
>with a force of how many dynes?"

Another item which is never met outside a schoolroom is the poundal

of force. This unit arose from the desire to have something to correspond

with the dyne in the metric system, for if the three fundamental concepts

of mechanics are to be mass, length and time, and if the pound (o.45359

prototype kilogram) is to be the unit of inertial mass, the poundal follows.

But there is no ordinary device which measures inertial mass. The pounds

that are measured by balances or spring scales are pounds of force, though

it is commonly thought that these devices measure quantity of matter. The

use of the slug of mass to avoid the poundal of force has already been

suggested. The slug can readily be made realistic to a student, but the

poundal never becomes anything more than an answer obtained to a numerical

exercise. The slug can be made a fundamental unit, and the pound of force

becomes a derived unit. Thus the poundal is superfluous.

Comparison with Advanced Mechanics.

Before attempting a choice of treatment of mechanics at the high-school

level, it may be well to summarize the accepted treatment at advanced levels.

In college it is customary to start with a statement of the three indefin-

able fundamental quantities, mass, length and time. From length and time

there is a mathematical development of the concept of acceleration, using

calculus and vector analysis.

Next the three laws of Newton are postulated, and there is a discussion

[1]/ Earl R. Glenn and Ellsworth S. Obourn. Instructional Tests in Physics
     page 28. Yonkers-on-Hudson: World Book Company, 1930.

of their exact content and their proper interpretation. It is implied that
they are based on observation and experiment, though it is an unusual treat-
ise which is in any degree specific on this score. [1] Thus is obtained the
relation F = M a, upon which is erected an elaborate mathematical super-
structure leading to the belief that this mathematics is in accordance with
various observational facts, without being in disagreement with any of them.
The treatment then proceeds to higher mathematics of value in the quantum
theory and in the theory of relativity, or to engineering applications.

At the high school level, the treatment must be considerably altered.
Probably every teacher believes that the use of the concept of force should
be introduced before it has been rigorously derived from the three funda-
mental concepts, mass, length and time, through the relation F = M a. The
distinction between vectors and scalars is bewildering to the beginner, that
is, between a concept like miles per hour of velocity, which may be north-
east or horizontal, and a concept like cubic feet of volume, which is
the same irrespective of any orientation. It is also bewildering to the
beginner to introduce algebraic derivations beyond one or two scattered
brief instances. Examples are found in the following chapters on pages 54
and 92. The treatment must be close to everyday experience. One can hardly
quarrel with the method of various authors of introducing water pressure or
levers early, to make the learner familiar with simple applications of force.

The obscurity of the treatment with regard to experimental demon-
strations leading inductively to underlying mechanical laws should be over-
come. In explanation of why this situation exists, the list of such

1/ Joseph S. Ames and Francis D. Murnaghan. Theoretical Mechanics. Boston:
        Ginn and Company, 1929. On pages 110 and 111 there is an excellent
        summary of the postulates and observations underlying Newton's second
        law.

experiments and demonstrations probably comprises no more than the following:

1. The Cavendish torsion balance experiment may be used to measure the force of attraction between metal balls, but is much too delicate for student use.

2. Experiments on motion caused by gravity, such as balls rolling down grooves, are used to obtain the relations between drop in elevation, velocity, and acceleration.

3. Atwood's machine, in which two slightly unequal masses are suspended from the ends of a cord passing over a pulley, illustrates the relation between force, mass and acceleration.

4. Conservation of energy and of momentum may be illustrated by experiments on impact, as with two or more balls suspended in a row from cords. One or more are drawn aside and released to swing and strike others.

5. Kepler's laws of planetary motion, though not derived from laboratory work, should probably be mentioned here.

In all experiments except the Cavendish one, high precision is impossible because of friction. The unavoidable effect of the motion of the earth on the precision of some mechanical experiments is small, but not always negligible. Hence a law such as conservation of momentum is believed to be exact in spite of the shortcomings of experiment.

In the body of this paper it is intended to introduce the significance of Newton's first and second laws, and the concepts of kinetic energy and momentum, from specific observational facts.

Comparison with Advanced Electricity.

Turning from mechanics to electricity, another group of problems arise when adapting the practice of advanced texts to the needs of preparatory

school students. A brief synopsis of theoretical electricity as taught at the college level, runs as follows. There are three topics at the start which vary in the order of presentation from author to author.

1. Coulomb's experiment on the forces between electric charges leading to the inverse square law. From this law there is a mathematical development of the concepts of electric field, of potential gradient and of capacitance.

2. The experimental justification leading to another inverse square law, namely of magnetic poles, and to the mathematical development of magnetic field intensity.

3. The concept of electric current as a flow of charges along a conductor. This is made evident by its electrolytic effect or its heating effect, either of which may be demonstrated.

After these three topics there follows a mathematical expression for Ampère's law, that is, the relation between current and magnetic field, often put in vectorial symbols. Unit current is defined from magnetic relations. There follows a mathematical superstructure leading toward electromagnetic induction, alternating currents, electromagnetic waves, and wide engineering applications.

When one turns to a group of high school physics texts, it is found that one[1] begins electricity and magnetism with static electricity, another[2] with magnetism, and a third[3] with voltaic cells. One introduces Joule's law of heating before Ohm's law of resistance and another after-

[1] John A. Clark, Frederick Russell Gordon and Francis W. Sears, Physics of Today, page 463. Boston: Houghton Mifflin Company, 1943.

[2] Charles E. Dull. Modern Physics, page 401. New York: Henry Holt and Company, 1945.

[3] William H. Michener. Physics for Students of Science and Engineering, page 387. New York: John Wiley and Sons, 1947.

ward. Some define the ampere by its chemical effect, others by its magnetic effect. Some define the ohm as the resistance of a certain column of mercury and derive the volt from the ampere and ohm by Ohm's law, while others define the volt from the Weston cell and derive the ohm from the ampere and volt. Some texts slur over any attempt to develop the laws inductively from observational facts, and make the study of electricity little more than practice in substituting numerical values in formulas that come from authority.

This state of affairs is regrettable unless it arises from conscientious attempts to teach electricity and magnetism psychologically, with attention to educational ideals, attitudes and appreciations. More likely, however, it arises from a variety of other causes such as the following:

1. Magnetism is introduced before static electricity, not after as logic requires, because the class can be set at simple, unfailing individual experiments with iron filings and compasses. On the other hand, the static experiments are apt to work badly in humid weather, they preferably use a somewhat expensive revolving glass plate machine, and it is not handy to arrange apparatus for tracing dielectric lines of flux.

2. Direct simplification of college electricity breaks down before it starts, because it employs the inverse square law which is probably above grade XII comprehension.

3. The author of the elementary text is confused by the intricacy of units used in advanced texts--cgem units, cges units, mks units, Heaviside-Lorentz units, international units, legal units and practical units.

4. The practical means of measuring current is by its magnetic effect, that is, using a galvanometer, hence some authors imply that magnetism should be treated before currents.

AN APPROACH TO

MECHANICS AND ELECTRICITY

The following section, running through page 99, is a prospective text to be given to students. The author feels it is qualitatively different from any text now available.

FOREWORD

The following chapters are written expressly for students of physics in the eleventh and twelfth grades of preparatory schools. The vocabulary and phraseology are restricted accordingly. They are written in the belief that the teaching of important portions of physics in these grades is neither logical nor psychological.

Energy as a topic is advanced to the very beginning of the chapter on mechanics, and introduced as the underlying principle accompanying physical and chemical changes, avoiding the loose and ambiguous 'definition' that energy is the 'capacity to do work'. (Work is a transitory form of energy during a process of conversion. Setting down 'work equals force times distance' is attempting to reason in a circle).

Several topics are presented along distinctly uncommon lines of thought. It is hoped thereby to clarify the reasoning of the learner, so that he reaches the laws of the subject more by realism than by indoctrination. Energy is preceded by no mechanical concepts other than those of matter and of space, and it is followed at once by the ideas of fields and of spontaneous conversions. This leads to the concept of force, and replaces the usual mumbo-jumbo that a force is a 'push or pull'. The manner of deriving the kinetic energy formula $(1/2m\ v^2)$, and the idea of force as the space rate of change of energy has much originality. Usually the relation $F = m\ a$ precedes $U = 1/2m\ v^2$ instead of following it, as in this text. In the chapter on electricity the treatments of reluctivity and of the quantitative relation between magnetism and current electricity have not previously been attempted at this level.

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Although it is planned that the student will not have to unlearn in

college anything he has found in these three chapters, yet an advanced

reader will recognize various generalized statements that would attain

strict accuracy only by inserting some qualifications. However, a rigorous

text could be written along similar lines.

Numerical exercises are not included, but of course the student

should be required to work through a selection of them. Conspicuous omis-

sions are numerous, including such topics as levers, inclined planes,

coefficient of friction, and center of gravity, for it is intended to replace

only limited portions of other texts. The answers to some, but not all, of

the test questions may be found within this text.

The chapter on Structure of Matter presents topics with which most

students will have become familiar before beginning physics. It is insert-

ed here for this reason, and because it is awkward to introduce these

topics only when first needed in mechanics and electricity. Science is

best learned by going over the same ground in successive years adding more

comprehensive and more difficult items.

Some readers of the chapter on Direct-current Electricity may notice

bizarre constants in certain formulas, particularly 43,770,000 on page 78

and 313 on page 88. These arise from the use of inches and pounds, rather

than centimeters and grams. The fact that there are so few of them may

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CHAPTER ONE
THE STRUCTURE OF MATTER

Introductory.

In the realm of physics and chemistry we observe and measure the behavior of our surroundings. First we obtain the facts, then we attempt to define concepts in terms of which the facts are to be interpreted. We assume that the same cause always produces the same effect, and that the best explanation of a given phenomenon is the one that is simplest, or that makes the fewest assumptions. When observations discover facts that correspond with each other under like conditions in similar experiments, we have a law. We attempt to express this law in the language of mathematics, for then it has a definite meaning, the same to all persons. Often mathematical operations may be performed upon it giving other helpful relations, and the numerical results of observed measurements may be substituted in the mathematical expression of the law to show its precision. Certain laws, for instance conservation of energy-mass and Faraday's law of electrolysis appear to be exact, for no deviations from them are found even with the most precise measurements. But with others such as Boyle's law, even though the law is quite useful, measurements made under some conditions show deviations from it of a few percent. With a few fundamental laws, including $F = M a$, verification by direct measurement with high precision has not been found possible, we nevertheless believe them to be exact. When an explanation of a range of phenomena may be made systematic, we have a theory.

In setting down an exposition of physics on paper we begin with the most axiomatic concepts and progress step by step without ever using a

concept not definable from the preceding. This is a virtually impossible
task, as there are many interrelations which become more and more complicated
the more thorough we are. But as far as such a procedure can be attained,
and we are able to classify our laws and theories over a considerable range
of facts, we have established physics and chemistry as sciences. These two
sciences with the accompanying mathematics, are the foundations of the use-
ful art of engineering.

Matter.

The most obvious physical fact is the existence of matter as recognized
by our senses of sight, touch and smell. All matter or materials may be
classified in various ways. Such subjects as zoology and botany deal with
living animal and vegetable matter, while chemistry and physics deal
generally with the properties of inanimate matter. It may be said by way
of description, rather than as attempt to define the indefinable, that
matter occupies space and responds to gravitation or earth-pull. One kind
of matter may be distinguished from another by physical properties, such
as color, flexibility or hardness, or by such characteristics as that some
kinds of matter may become magnetic or luminous.

The term used in measuring whether one object has more matter than
another is mass. (It is preferable to avoid the word 'weight' until the
distinction between mass and weight has been discussed later.) Quantity
of matter is manifested in more than one aspect, the simplest approach
being an examination of the gravitational aspect. For example, if two
blocks, say one of iron and one of magnesium, just equalize each other on
a balance, they have the same mass, that is, the same amount of gravitational

attraction. With this device, if two such blocks, proved to be of equal mass, are both placed on one pan, then a heavier block may be placed on the other pan and adjusted in content by adding or removing material until balance is obtained, when it will have twice the mass of either of the first two blocks. By continuing such a process, a standard set of measuring

Balance   Set of measuring masses
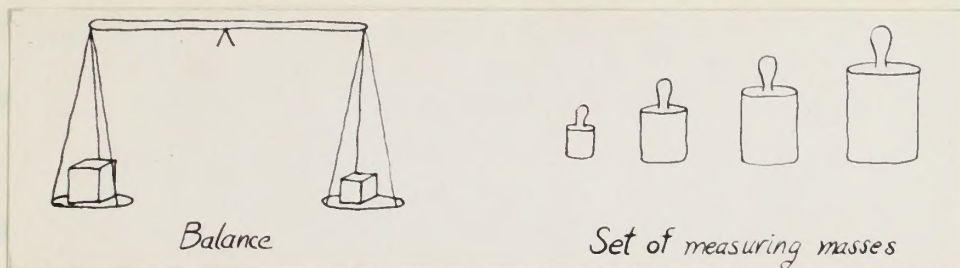
blocks may be made up, having masses in convenient multiples of each other, and used for measuring the mass of any other object.

No better way has been accepted for standardizing the unit of mass than the preservation in some government bureau of a particular piece of metal by which all other masses may, in principle, be measured. There is preserved in Washington a block of metal which has, by definition, a mass of 2.205 pounds (one kilogram).

Space.

The existence of space up and down, ahead and behind, to the right and to the left, is axiomatic, that is, the idea is accepted without proof. It is evident that there are great units of space between the earth and the moon or stars, and small units of space between grains of powder. Space is recognized as length in lines having one dimension, as area in surfaces having two dimensions, and as volume in objects having three dimensions.

The unit of length is standardized in the same way as the unit of mass. There is preserved in Washington a bar of metal with two scratches across it, one near each end, and the distance between the scratches is defined as

39.37 inches (one meter), when the bar is packed in melting ice.

The term 'density' is an example of a concept which is not axiomatic, for it is definable in terms of volume (length cubed) and of mass. It is used to specify whether a given kind of matter is heavy or light. By way of illustration, wood will float on water because it has less density than water. The density of any specimen may be computed by dividing its mass by its volume. A convenient unit of density is pounds per cubic foot.

Physical and Chemical Properties.

Various materials are distinguished from each other by such properties as color, odor, hardness, ductility, solubility, and by their condition of being solid, liquid or gaseous. These are a few examples of what are known as the physical properties of matter. Some gases will burn, while others will extinguish fire, and these characteristics are examples of chemical properties.

To the chemist a pure substance is one having definite, uniform properties under definite conditions. All samples of a given substance, when conditions such as temperature or pressure are the same, are alike. Distinction should be made between a material or substance, and an object or body. Thus cups (objects) may be made from iron or silver (substances), and from iron (a substance) may be made knives, screws, or rails (objects). Found in great quantity on the earth, and well known to all humans, is the substance water. Ordinarily water is a colorless, odorless, tasteless, and somewhat volatile liquid.

A chemical reaction is a change or process into which one or more substances enter, and one or more other substances having quite different properties are produced. About 5000 years ago it was discovered by chance that metallic tin or copper could be obtained from certain ores by

82.97 inches (one meter), when the bar is cooled in melting ice.

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roasting. This process involves a chemical change. About 3000 years ago
it was found that iron could be obtained from certain ores by roasting in
the presence of charcoal.

Some substances such as the metal sodium or the gas chlorine are
chemically active, so that they will enter into a reaction with a wide
variety of substances with which they may come in contact. Other substances
such as the metal, gold, or the gas, nitrogen, are relatively inert, and no
chemical change will occur upon contact with any except a very few substan-
ces.

Elements.

As the early chemists were experimenting with chemical behavior it be-
came evident that some kinds of matter were simpler than others, and indeed
for certain cases further decomposition or simplification appeared impossi-
ble. Materials which cannot be chemically analyzed into simpler components
have become known as elements. The same elements that exist in the sub-
stances entering a chemical reaction are present in the products remaining
afterward. The study of many substances has revealed only about 90
different elements, including about 35 which are quite familiar, another
35 which are not so familiar but are available at some expense for
specialized purposes, and about 20 which are rare laboratory curiosities.

The elements may be divided into two broad groups, the metals and the
nonmetals, the latter group being often subdivided by setting off the
gases from the other nonmetals. The metals, including sodium, magnesium,
zinc, copper, and mercury, are distinguished because most of them are
relatively dense, because a fresh surface is lustrous, and particularly be-
cause they are conductors of heat and electricity. The nonmetals include

sulfur and carbon, and among the gases are oxygen, hydrogen, nitrogen, and chlorine. A few elements are found in the ground in a reasonably pure state but most are separated only by chemical analysis.

Mixtures and compounds.

The characteristics of a mixture are readily illustrated by an example. If zinc dust and powdered sulfur be stirred together there is formed what is known as a mixture because it may be readily separated into its components by such physical processes as dissolving and

Funnel
containing
residue

Ring clamp

Stand

Beaker
containing
filtrate

Filtering a suspension

evaporating. The mixture may be stirred into liquid carbon bisulfide which dissolves the sulfur but not the zinc. Afterwards by pouring through filter paper which has been rolled into a cone shape and inserted into a funnel as shown in the diagram, the zinc is left as a residue on the paper, and the filtrate of sulfur and carbon bisulfide may be allowed to stand. Then the carbon bisulfide soon evaporates leaving the sulfur, so the whole operation is back where it started.

If acid be added to the dry mixture of zinc and sulfur in a test tube, an odorless gas is given off (hydrogen). But if a mixture of the two be placed on an asbestos pad on a tripod, and the Bunsen flame be played on it, a vigorous reaction takes place giving off light, and a white compound remains which has none of the physical properties of either zinc or sulfur. Finally, if this white substance be placed in a test tube and acid be added, a gas with a very disagreeable odor is given off (hydrogen sulfide).

Real progress in chemical theory began about 1770 when Lavoisier in
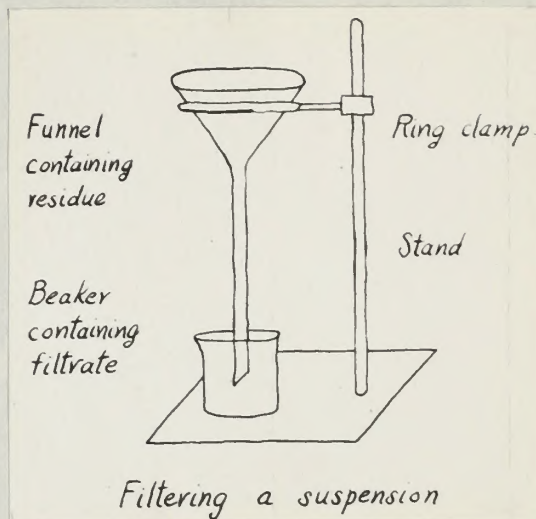
France and Black in Scotland used the balance to measure the quantity of matter in chemical reactions. Due to the study they initiated, it has been learned that any compound is composed of a small number of elements, usually two, three or four, chemically combined in some definite proportion by mass. Any particular compound is always composed of exactly the same elements combined in exactly the same proportions, regardless of any changing conditions such as temperature or pressure. For example, any sample of table salt is always 39.3 percent sodium and 60.7 percent chlorine, no matter how or where the sample is obtained. On the other hand, the composition of any mixture may vary slightly or considerably.

An important related fact is that the mass of the ingredients entering into a chemical reaction is exactly equal to that of the products resulting from it. This has been tested experimentally with the utmost precision, thus establishing the law of conservation of matter. However, when a reaction releases energy as in the atomic bomb a loss of mass occurs. There is a relation between the law of conservation of energy to be introduced in the next chapter and the law of conservation of mass, so that fundamentally they are aspects of one underlying law.

Chemical compounds are broadly divided into two classifications, the organic compounds, all containing carbon as one constituent, of which there are probably half a million or more, and the inorganic compounds, generally not containing carbon, of which there are a far smaller number.

Various substances, including sugar and salt, dissolve in water to form solutions. These are mixtures, not compounds, because they are not necessarily combined in any fixed proportion; for instance, the amount of sugar dissolved in water may be much or little. Some substances which will

not dissolve in water will dissolve in something else. For example sulfur
is insoluble in water but soluble in carbon bisulfide. The dissolving
substance is called the solvent. Some of the characteristics of a solution
are that the dissolved substance, called the solute, does not settle out
by gravity no matter how long the solution stands, and the individual
particles of solute cannot be seen in the solution with a microscope.

A suspension is a liquid containing a finely divided, insoluble solid,
an example being muddy water. The individual particles of solid are visible,
at least with a lens, and they tend to settle by gravity.

Molecules.

A stream of water may be regulated so as to flow from even a tiny jet
and yet appear to be composed of continuous matter. On the other hand a
stream of sand may appear to be continuous if it is coming at high speed
from a large nozzle, but if it is a slower stream from a smaller opening,
it is seen to be made up of individual grains.

But there are reasons for believing that even water, or any other
substance, if subdivided finely enough, has a structure of individual
members known as molecules. The molecule may be defined as the smallest
unit of a substance which possesses the physical properties of the
substance. Investigations of the structure of matter have been active
during the twentieth century, and much interesting and important evidence
has accumulated that even molecules are not the ultimate particles, but are
composed of atoms which in turn are composed of electrons (and certain
other particles). Molecules are too small to be seen with an optical
microscope, although silhouettes of some of them have been obtained with
an electron microscope. Some molecules are about $1/10^8$ inch diameter.
Gas molecules have masses of about $1/10^{25}$ pounds.

Kinetic-molecular Theory.

It is believed that the molecules of all substances are in ceaseless
motion, the activity being greater at high temperature than at low tempera-
ture. The spaces between the molecules are relatively large, and each
molecule moves with high speed through short paths in these spaces. In a
solid body each molecule vibrates but stays in a relatively small volume of
space. The geometrical patterns of crystals of salt, sugar and minerals
are due to the arrangement of the positions about which the molecules vibrate.
Such objects appear solid in spite of the relatively large spaces between
the molecules in somewhat the same way as a rapidly revolving wheel will not
permit a stick to be inserted between the spokes. By contrast, the positions
and motions of the molecules in a gas are utterly random. They fly about
colliding with each other and with the walls of the container somewhat as
loose pingpong balls violently shaken about in a waste basket. When a gas
is contained in a cylinder with a piston, the blows struck by the molecules
on the piston tend to push it out, or if the piston be pulled out as in a
vacuum pump, the average distance between the molecules immediately increases
so that the gas completely fills the new space.
In a liquid, the freedom of the molecules is
intermediate between the condition of a solid
and the condition of gas.
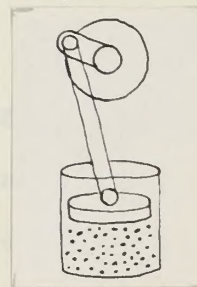
Some of the evidence for believing that there are empty spaces between
molecules is the expansion of liquids when they are changed to gases. For
example, water expands to about 1600 times its volume when it changes to
steam. The compressibility of gases is not believed to be due to any sig-
nificant change in the volume of the molecules themselves, but to a decrease

in the space between them. When a solution is made of such substances as alcohol in water, or sugar in water, the volume of the solution is less than the sum of the volumes of the ingredients, because the molecules of one have become interspersed between the molecules of the other.

Some of the evidence that molecules are in motion includes the diffusion of any gas into a space already occupied by another gas, so that shortly after mixing two gases in a closed vessel, whether a chemical reaction takes place or not, all samples taken from the vessel are identical. The injury to the finger when a very hot solid is touched is due to the violent motion of the molecules of the solid causing the cells of the flesh to vibrate too fast to continue living.

Another phenomenon explained by molecular motion may be demonstrated by dropping a few tiny crystals of a solute such as potassium permanganate into a tall jar of water and leaving it undisturbed. The crystals gradually dissolve and the deep purple color from them eventually spreads uniformly throughout the water in spite of the tendency of gravity to keep the permanganate at the bottom.

Reactions Between Gases.

About 1811, Gay-Lussac obtained an important clue regarding molecules, namely that in a chemical reaction involving gases the combining volume relations are small whole numbers. For instance, one unit of volume of hydrogen reacts with one unit of chlorine to yield two units of hydrogen chloride gas. This seems reasonable enough, but it is also true that two units of volume of hydrogen react with one unit of oxygen to yield two units of steam.

To demonstrate such a reaction, a graduated tube, closed at one end,
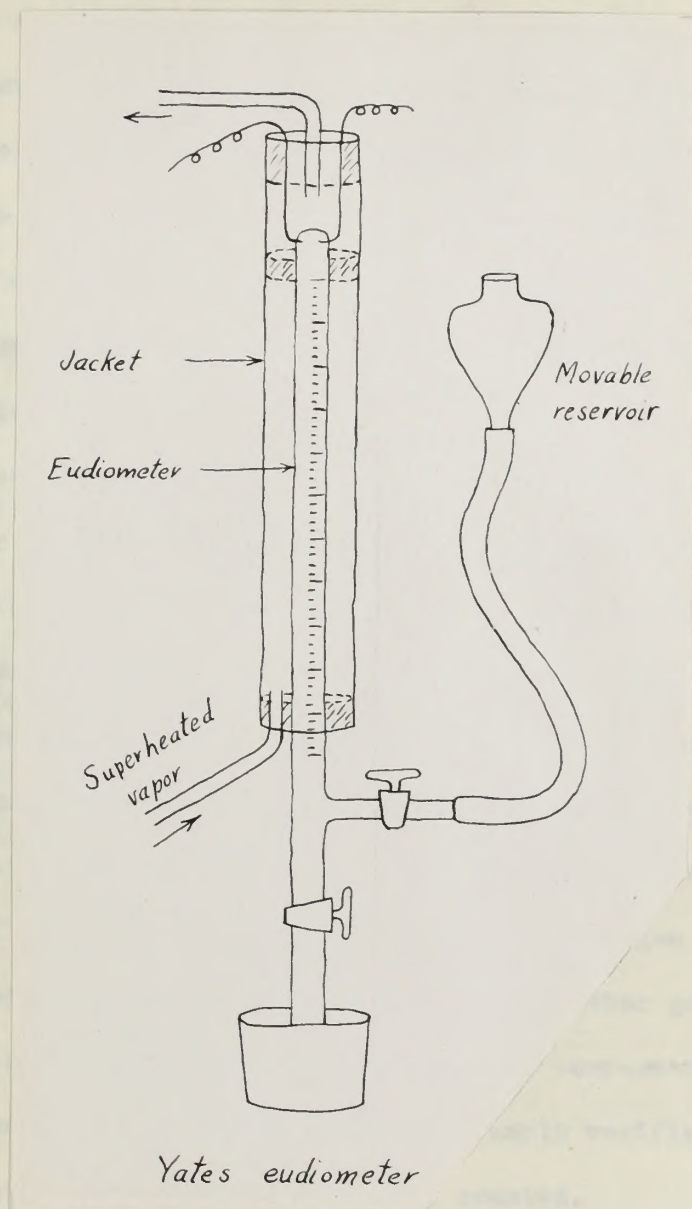
forms the principal part of the apparatus shown in the diagram, page 32.

This tube, called a eudiometer, has wires sealed in to form a spark gap. It is filled with mercury and set up vertically, open end down into a trough of mercury. The

Jacket

Eudiometer

Superheated vapor

Movable reservoir

Yates eudiometer

forms the principal part of the apparatus shown in the diagram, page 32.*

This tube, called a eudiometer, has wires sealed in to form a spark gap.

It is filled with mercury and set up vertically, open end down into a trough

of mercury. The side arm connects by a flexible rubber tube with a

reservoir of mercury which is moved up or down to maintain the same level

inside as outside the eudiometer whenever the volume of gas is being mea-

sured. Since the product of this reaction is to be steam, the eudiometer

is surrounded by a glass jacket which is kept slightly above 100° C. This

is done by passing through the jacket the superheated vapor from a boiling

solution of calcium chloride.

When all is set up, oxygen is introduced through the open, lower end
of the eudiometer until 10 ml. of mercury are displaced. Then 20 ml. of
hydrogen are similarly introduced, making 30 ml. of mixture. The spark is
passed, the mixture explodes, and 20 ml. of steam remain. (Later, upon
cooling the apparatus, the steam condenses to a drop of water). In explana-
tion of such facts, shortly after 1811 Avogadro proposed the next theoretical
step, namely, that gases react in simple proportions by molecules, and that
a given volume of any gas, such as a cubic foot of nitrogen must contain
the same number of molecules as a cubic foot of any other gas, such as
carbon monoxide (under corresponding conditions of temperature and pres-
sure). More recently this hypothesis has been amply verified in various
ways, and indirectly the molecules have been counted.

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* Taken from G. Fowles, Lecture Experiments in Chemistry, Third edition,
Philadelphia, The Blakiston Company, 1947. This reference on page 349
gives important details to insure the success and safety of this
demonstration.

Atoms.

During the eighteenth century, chemists noticed not only that every compound has a definite composition, but that there are pairs and groups of compounds in which the proportions may readily be expressed as multiples of each other. For instance, three of the compounds of carbon with hydrogen may be analyzed and shown to have percentage compositions as stated in the left hand columns.

percent of			proportion of	
carbon	hydrogen		carbon	hydrogen
75.0	25.0	methane	6 parts in 8	2 parts in 8
85.7	14.3	ethylene	6 parts in 7	1 part in 7
92.3	7.7	acetylene	12 parts in 13	1 part in 13

But when it is noticed that these percentage compositions may be numerically rearranged as in the right hand columns, the multiples, such as 6 and 12 or 1 and 2, appear significant.

It was Dalton, about 1808, who first explained such multiple proportions by saying that each molecule of a substance is composed of a fixed, whole number of atoms of the elements; in other words, that matter exists in units smaller than molecules. Each molecule contains elements united in simple proportions by atoms, and any atom preserves its individuality during a chemical reaction. As part of his theory, Dalton stated that all atoms of the same element are alike in mass, and different in mass from the atoms of any other elements.

Returning to the experiment in which two units of volume of hydrogen react with one volume of oxygen to yield two volumes of steam, let equal units of volume be represented in the diagram by squares, let each atom of hydrogen be represented by a circle and each atom of oxygen by a triangle.

2 volumes   1 volume   2 volumes
of hydrogen   of oxygen   of steam
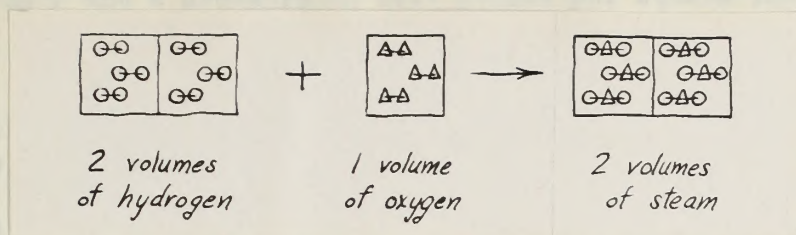
Now since each unit of volume contains the same number of molecules, try
using three molecules in each square, but the count cannot be made to come
out correctly unless each molecule of hydrogen and of oxygen contains two
atoms, and each molecule of water contains two atoms of hydrogen and one of
oxygen. By investigations of this sort, it has been learned that each

molecule of the gaseous elements hydrogen, oxygen, nitrogen, chlorine and

a very few others, contains two atoms of the element. But for metals and

other elements the molecule and the atom are identical.

Atomic Weight.

Although the term 'mass' is superior to 'weight' when refering to
quantity of matter, it seems wise in this paragraph to follow chemical
custom by using 'weight'. By Avogadro's hypothesis, a unit of volume of a
gas contains a definite number of molecules, and since each molecule has a
definite and unique weight, and further as density is the weight of unit
volume, then it follows that the density of any gas is proportional to the
relative weight of a molecule of that gas. Thus a scale of molecular
weights may be established by measuring the densities of gases, and since
the elementary gases are diatomic, there may be computed a scale of rela-
tive atomic weights, that is, for various elements the weights of their
atoms in proportion to each other.

Measurements of the densities of the light gases require much ingenuity
in designing apparatus, and great skill in manipulating it. The results

show that at 32°F and a pressure of 14.7 pounds per square inch, the density of

-hydrogen is o.00561 pounds per cubic foot
-nitrogen is o.0781   "   "   "   "
-oxygen is o.0892   "   "   "   "
-chlorine is o.2007   "   "   "   "

The fact that no substance is known with a density less than hydrogen suggests that it be taken as a relative standard by calling its atomic weight one. Then, because its molecule contains two atoms, its relative molecular weight is 2, and other relative molecular weights become

$$\text{nitrogen} \quad \frac{0.0781}{0.00561} \times 2 = 28 \qquad \text{oxygen} \quad \frac{0.0892}{0.00561} \times 2 = 32$$

$$\text{chlorine} \quad \frac{0.2007}{0.00561} \times 2 = 71$$

Hence the atomic weights of these gaseous elements are (roughly)

nitrogen $28/2 = 14$
oxygen $32/2 = 16$
chlorine $71/2 = 35.5$

Formulas.

For each element an abbreviation has been internationally adopted consisting of one or two letters, such as C for carbon, H for hydrogen, O for oxygen and Cl for chlorine. For the elements known to the early chemists, they are from the Latin word for the element, such as Fe for iron (ferrum). Since any molecule contains whole numbers of the atoms of certain elements, the formulas for compounds are abbreviated after the following manner: H_2O means that each molecule of water contains two atoms of hydrogen and one of oxygen. (Where a subscript is omitted, as after O, the number one is understood). The formula for ethylene is C_2H_4, meaning that each molecule contains two atoms of carbon and four of hydrogen.

The question arises as to how proper subscripts are determined; for instance whether ethylene is C_2H_5 instead of C_2H_4, or whether there is any objection to writing it in the obviously simpler form $C H_2$, instead of C_2H_4. Such questions bothered chemists seriously from the time of Dalton, about 1808, to Cannizzaro, about 1860. Any brief and convincing verification of the subscripts in the formulas for most compounds is hardly possible. However, the foregoing methods provide an attack on the formulas of gaseous compounds, and on the atomic weight of elements composing them.

Consider the problem of the formula for ethylene, and of the atomic weight of carbon. Measurement shows that the density of ethylene is o.078 pounds per cubic foot, hence its molecular weight is

$$\frac{o.078}{o.00561} \times 2 = 28$$

Measurement also shows that its composition is one part hydrogen to seven parts carbon, or 4 parts to 28. Since the atomic weight of hydrogen is one, there must be 4 atoms of hydrogen in a molecule of ethylene. The remainder of the molecule is carbon, but the 24 parts might represent 1, 2, 3, 4, 6, 8 or 12 atoms of carbon corresponding to an atomic weight of 24, 12, 8, 6, 4, 3 or 2 respectively. So another gaseous compound of carbon such as carbon tetrachloride is investigated, in order to determine the atomic weight of the carbon component. From measurements of its density and composition, its molecular weight is determined as 154, of which 142 parts are chlorine and 12 parts are carbon. Since the atomic weight of chlorine is known to be 35.5, it follows that there are $142/35.5 = 4$ atoms of chlorine in a molecule of carbon tetrachloride. The remaining 12 parts of carbon eliminate the possibility that its atomic weight is either 24 or 8, for neither will divide evenly into 12. If the atomic weight of

carbon is 12 the formula for ethylene is C_2H_4 and for carbon tetrachloride
is $C Cl_4$. There remains the possibility that the atomic weight of
carbon is 6 or less, and that the molecules of these two compounds are
more complicated. Cannizzaro carried the reasoning to this point about
1860, and since then other evidence, such as the periodic table of
elements, has confirmed 12 as the correct atomic weight of carbon.

Electrons.

There is evidence not only that matter is composed of molecules too
small to be seen with an optical microscope, and that molecules are com-
posed of atoms very much smaller than themselves, but that even atoms are
composed of particles still very much smaller. Although much of the explan-
ation is too advanced to be made in detail at this point, it is helpful to
have the general picture in mind.

About 1869 Crookes observed that under certain conditions an electrical
discharge passed through an evacuated tube produces a shadow effect which
was explained as due to 'cathode rays'. On another occasion about 1883
Edison observed that if an evacuated glass bulb contains a heated filament
and a separate metal plate, a current of electricity may be passed in one
direction between the plate and the filament but not the other. (In radio
this became known as a diode tube). These were among the first of a series
of phenomena which J. J. Thomson in 1899 attributed to the emission or
shooting off of electrons from atoms. Other particles have been found in
atoms; the proton by Rutherford in 1911 and the neutron by Chadwick in 1933.

The following 'mental images' of atoms with the electrons they contain
have been suggested by various authorities. Although widely taught, they
should be taken with some reservations, for the theory of atomic structure
is still incomplete, and those knowing the most about it often feel that

the best approach to the truth is by highly complex mathematical expressions, rather than any image or model however ingenious.

A hydrogen atom contains a nucleus in which practically all its mass is concentrated, composed of one proton. Around the nucleus one electron of relatively negligible mass moves in an orbit possibly something like the diagram, that is, varying from an elongated ellipse to nearly a circle. The carbon atom contains a nucleus with 6 protons and 6 neutrons. Around the nucleus two electrons move in orbits similar to the one hydrogen electron and four more electrons move in relatively larger orbits, possibly giving the atom somewhat the shape of a tetrahedron. The sodium atom contains
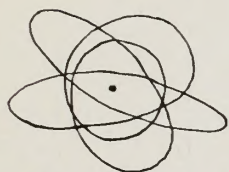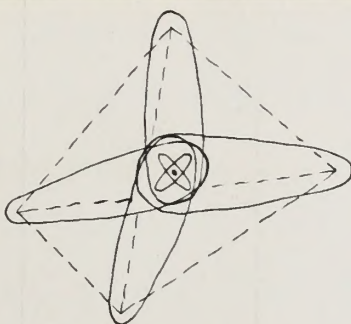
Hydrogen atom   Carbon atom   Sodium atom
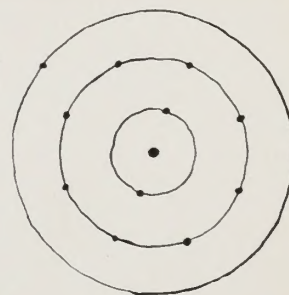
a nucleus with 11 protons and 12 neutrons, surrounded by 11 electrons. The orbits of two electrons are similar to that of the hydrogen atom, and the orbits of eight are similar to the outer four in the carbon atom. There is one electron moving in a relatively larger orbit. In an excessively simplified form this is shown in the diagram.

Electric Charges.

Under some conditions, when two dissimilar bodies are taken out of contact with each other they acquire the property of attracting or repelling various objects. For example, after a fountain pen is rubbed on a woolen sleeve it will pick up bits of paper. (Friction has very little to do with such effects, the advantage of rubbing being more intimate

contact).

Let a vulcanite rod be rubbed with fur and then suspended by a fine
dry thread. It is found to be repelled by another vulcanite rod similarly
rubbed, but if a glass rod which has been rubbed with silk be brought near
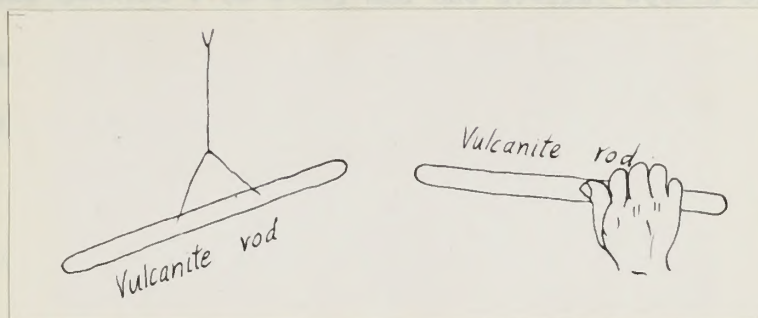
the suspended vulcanite rod, they attract. (The atmospheric humidity in
the room where such trials are made should be low for good results, and
the rods and cloths should be dry and warm. The effects can hardly be
observed in humid, summer weather).

The vulcanite rod and the glass rod are said to be 'charged' after
contact with the fur and silk. Obviously they were charged in opposite
ways, since two vulcanite rods or two glass rods will repel each other,
but a vulcanite rod and a glass rod will attract. To distinguish them,
the charge on the glass is said to be positive, and that on the vulcanite
negative. Observations readily show that unlike (+ and -) charges attract
each other and that like (+ and + or - and -) charges repel. Either end
of a charged vulcanite rod is attracted by a charged glass rod, in other
words, the charge on the whole of a body may be of one sign, negative in
the case of the vulcanite.

It is believed that in the act of separating two bodies such as a
glass rod and a silk cloth some electrons are lost by one and gained by
the other. A body has one kind of charge when it has more, and the
opposite kind when it has less, than its normal number of electrons.

It can be shown that charges are always produced in equal and opposite
pairs, in other words, there is conservation of charge, just as there is
conservation of energy and of mass. The unit of charge is the coulomb,
named for Charles Coulomb 1736-1806, and one coulomb equals 6.3×10^{18}
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Principles--The Structure of Matter.

Quantity of matter is termed mass, and is measured on a balance by gravitational attraction.

Space is recognized in one dimension (length), in two dimensions (area), and in three dimensions (volume).

Density specifies whether a material is heavy or light.

Substances are distinguished, one from another, by their physical and chemical properties.

An element is a substance which cannot be chemically decomposed.

A compound contains two or more elements chemically united in a fixed proportion by mass. A mixture contains substances united in variable proportions.

The smallest unit of a substance which possesses its physical properties is a molecule.

Molecules of all substances are in ceaseless motion. This motion is restricted primarily by intermolecular forces in solids, by gravitational forces in liquids, but is entirely random in gases.

In a chemical reaction involving gases, the combining volume relations are small whole numbers.

A given volume of any gas contains the same number of molecules as the same volume of any other gas (under corresponding conditions of temperature and pressure).

The smallest unit of an element which does not divide in a chemical reaction is an atom. Any molecule contains elements united in simple fixed proportions by atoms.

Symbols for atoms are used as abbreviations in writing the formulas for

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of each element in a molecule.

The atom of each element has its characteristic weight, different from that
of the atom of any other element. Atomic weights are expressed in
relation to each other. (Expressed in ounces or grams they are
inconveniently small).

Molecular weights of gases and atomic weights of elements forming gaseous
compounds are determined from measurements of density and of percentage
composition.

The atom of an element has a central nucleus containing protons and neutrons.
This is surrounded by electrons moving in orbits.

In the act of separating two dissimilar bodies some electrons may be gained
by one and lost by the other, thus causing the bodies to become
charged. Such bodies exhibit attraction and repulsion.

Test--The Structure of Matter

If the statement is correct, write 'true' on the line at the right. If it
    is incorrect, write the term that must be substituted for the under-
    lined term, to make the statement correct. The first one has been done
    as a sample.

Mercury is a solid at ordinary temperature.   liquid

The nucleus of an atom is composed of electrons and protons.   _____

The densities of gases are proportional to the weights of

    their molecules.   _____

The oxide of a metal has different properties from the pure

    metal.   _____

The reaction of another element with sulfur yields a substance

    weighing more than the sulfur.   _____

Compounds are formed by the chemical combination of two or more

    elements.   _____

A mixture may be separated by physical means.   _____

A liquid occupies a definite area, but has a variable shape.   _____

A solid retained on the porous paper after filtering is called

    a filtrate.   _____

Hydrogen resembles oxygen in most of its physical properties.   _____

        *   *   *   *   *   *   *   *   *   *

Each statement is followed by various ways or completing it, only one of
    which is correct. Mark X in front of the correct way.

A trial made to confirm or disprove something doubtful is an example of--

        ( ) scientific reasoning ( ) experimentation ( ) calculation
        ( ) engineering

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*   *   *   *   *   *   *   *   *   *   *

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Lead sinks in water because -- ( ) any metal sinks in any liquid ( ) elements sink in compounds ( ) it does not dissolve in water ( ) it has greater density than water.

Taking the density of air as o.08 pounds per cubic foot, the volume in cubic feet occupied by 2.4 pounds of air is -- ( ) 30 ( ) 300 ( ) o.192 ( ) 3.33.

A substance which dissolves another substance is called -- ( ) a hydrate ( ) a solute ( ) a solution ( ) a solvent.

A solid dissolved in water may be recovered by -- ( ) evaporation ( ) filtration ( ) reaction ( ) synthesis.

An element may -- ( ) combine with another to form a compound ( ) be composed of unlike atoms ( ) be decomposed by strong heating ( ) always be distinguished from other elements by boiling point.

A substance that may be analyzed by physical means is -- ( ) an element ( ) a compound ( ) a mixture ( ) an acid.

Of the following, that which is formed from other substances by chemical reaction is -- ( ) a solution ( ) a compound ( ) a mixture ( ) an alloy.

Of the following, the lightest gas is -- ( ) hydrogen ( ) oxygen ( ) nitrogen ( ) carbon dioxide.

The elements are more often found in nature -- ( ) as solids ( ) as liquids ( ) free and uncombined ( ) in the form of compounds.

The smallest possible particle of sugar is the -- ( ) atom ( ) electron ( ) compound ( ) molecule.

The first to note that total weight does not change in a chemical reaction was -- ( ) Dalton ( ) Avogadro ( ) Lavoisier ( ) Berzelius.

Two molecules of water contain -- ( ) two atoms of ice ( ) two volumes of steam ( ) two atoms of hydrogen and two atoms of oxygen ( ) four atoms of hydrogen and two atoms of oxygen.

An atom is believed to -- ( ) have an electrically charged nucleus ( ) have protons whirling outside the nucleus ( ) consist entirely of protons and electrons ( ) contain free electrons in the nucleus.

CHAPTER TWO
ENERGY AND THE CONCEPTS OF MECHANICS.

Energy.

Although it cannot be seen, felt, or measured in any direct way, there is probably no concept in physics or chemistry more important than that of energy. Every variation in the properties of matter is to be attributed to an energy change. Some physical and chemical properties of matter have been mentioned in the preceding chapter. There are many ways of changing these properties. Water will change to ice if placed in a refrigerator, a rod of malleable iron will become magnetic and pick up tacks if a permanent magnet be brought near it, a platinum wire will become luminous if held in a gas flame. These are examples of physical changes, because the identity of the substance is not lost. Usually physical changes may be reversed more or less easily. The ice will melt to water again when left in a warm room, the malleable iron loses its magnetism when the permanent magnet is withdrawn, the platinum wire no longer gives off light when removed from the flame.

On the other hand, a change which produces a different substance is known as a chemical change. For example, if white crystalline sugar be put on a hot stove it turns to a brown liquid and, with further heating, to a black solid which even the most skilful chemist could not easily return to the usual form of sugar.

Energy exists in several forms, the most common of which is heat (thermal energy). Kinetic energy accompanies motion, and is possessed by any moving body. Chemical energy is intimately bound up in the structure of matter and is often released in the form of heat during a chemical

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(thermal energy). Kinetic energy accompanies motion, and is possessed by

any moving body. Chemical energy is intimately bound up in the structure

of matter and is often released in the form of heat during a chemical

change. Radiant energy from the sun warms objects on the earth.

There are numerous ways of converting energy from one form to another.
For example, kinetic energy is frequently converted to heat by friction.
Engineering and physics are largely concerned with the conversion of energy
from one form to another. A good illustration can be found in the steam
power plant, where the boiler converts chemical energy from coal into heat
energy in steam. The boiler supplies the steam to an engine which converts
the heat into rotational kinetic energy of the shaft. Attached to the re-
volving shaft may be an electric dynamo which effects further conversion.
Energy may be usefully obtained from waterfalls, from burning coal, from
electric batteries and from muscular effort.

In the process of conversion of energy from one form to another, if
all the energy entering into the process in various ways be measured
against all energy liberated, none is ever gained or lost, regardless of
the method of conversion. This fact is known as the law of conservation
of energy. Today this is believed to be true because the most diligent
search has never revealed any exceptions, although in the release of atomic
energy from such an element as uranium, conservation of mass and conserva-
tion of energy are aspects of one underlying principle.

Fields of Energy--Attraction.

Numerous instances may be cited in which a group of two or more bodies
exhibits properties which vary with size, shape and relative position. One
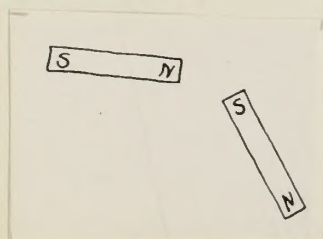
such property is that of attraction, and a phenomenon
closely related to it called a field of energy. An
instance of attraction is that of magnetism. Bar
magnets of hardened steel are familiar objects, and it

is well known that the two ends appear to be opposite in certain respects, so that one end is often marked N and the other S (north seeking and south seeking if suspended so that the bar can swing). With two such magnets, if they be placed in the position shown, there is an attraction between the two nearest ends. In explanation of this phenomenon, it is said that a field of energy exists in the space surrounding the magnet, and iron filings are often used to demonstrate the shape of this field. Part of the evidence that the field surrounds the magnet is that if, while two magnets are held in the position shown, a metal wire be passed through the space between, though without touching either of them, an electric current may be detected in the wire.

There is a still better known instance of attraction, namely that of gravitation. It seems to be an outstanding property of mass that any body attracts any other, the intensity of attraction varying with size, shape and relative position, Newton announced this as the underlying principle of the solar system in 1672. Between two objects in a laboratory the attraction is extremely slight, but in 1797 Cavendish devised apparatus with which he measured the attraction between gold and lead spheres. There is mutual attraction between the earth and any ordinary object, but the earth is so very large in relation to all bodies in human experience that no one is conscious of any effect on the whole earth, but only of attraction toward the earth. The earth may be said to be surrounded by a field of gravitational energy. This energy is interpreted as a force which acts on all bodies in this field, tending to move them toward the earth. The energy stored in this field is increased and a force must be exerted when any

object is lifted to a higher elevation, and the energy is diminished if the

object is lowered again. An example is the tall clock with the weights that wind up. The descent of the weights supplies energy which keeps the clock going, and when the weights are all the way down the clock stops.

Elastic energy is a form which is due to shape and relative position. A watch is driven by a spiral spring. By winding up the spring the shape and relative position of the coils are changed, and elastic energy is stored which is gradually converted into trifling amounts of heat by the slight friction of the running of the watch.

Order of Forms of Energy.

Among the various forms of energy, some may be considered to be of a higher order than others. In the case of the more highly ordered forms, the amount of energy depends on the size, shape and relative position of the bodies or particles concerned, that is, on geometrical arrangement. For example when an iron piece is close to a magnet the attraction is much greater than when it is removed even a moderate distance. Shape and geometrical position are significant in the gravitational, elastic and dielectric* forms where energy appears to be most highly ordered, and to have a spontaneous tendency to convert to the less highly ordered forms. The kinetic and magnetic forms are intermediate, kinetic energy depending on ordered motion of the bodies or particles involved, and magnetic energy depending on ordered motion of electrons. Thermal or heat energy is the lowest form, and depends on random, that is, quite disordered motion of molecules.

The higher forms of energy convert to the lower forms through the

*Dielectric energy is described in the chapter Direct-current Electricity

intermediate forms. For example, the natural tendency of gravitational or elastic energy to convert into the lower form of heat energy takes place by way of kinetic energy. Force is a familiar phenomenon often accompanying such conversions of energy. Among the more familiar forces are those due to gravitational attraction toward the earth, to muscular exertion and to friction.

As an example of the attraction of gravity being a force which exists during a conversion of energy from gravitational to kinetic, consider a block sliding down a smooth incline onto a rough horizontal surface. While the block is sliding down the incline the force of gravity moves it and gravitational energy is being converted into kinetic energy. While the block is coming to rest on the rough surface, the force of friction stops it, and kinetic energy is being converted into heat.
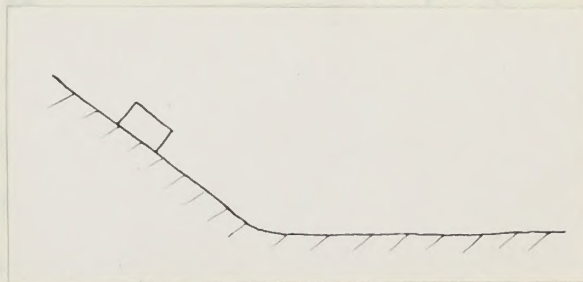
Force.

All forces are due either to attraction in a field of energy, or to a conversion of energy such as the instance of the sliding block. The existence of a force requires the influence of another body. The concept of force then implies the mutual action of two bodies, hence forces always exist in equal and opposite pairs (Newton's third law).

It is believed that the gravitational fields of planets smaller or larger than our earth have corresponding less or greater intensity than that of our earth. For example on the smaller planet Mars a 10-pound

body at an elevation of 2000 feet above the ground stores less gravitational energy than a 10-pound body at an elevation of 2000 feet above the surface of our earth. In such a case the mass has not changed, nor has the elevation, but the amount of gravitational force has changed. Hence it can be readily seen that the amount of gravitational energy stored in the field by lifting a body equals the force (not the mass) times the difference in elevation.

Consider the effort to pull out a coil spring. The greater the effort exerted to extend the spring, the more its shape and the relative position of its coils are changed. Beginning from the free or relaxed position, more and more elastic energy is stored in the spring as it is stretched, but this conversion of energy is reversed when the spring returns to its relaxed shape. If apparatus consisting of a spring with a mass hanging from it were moved from sea level to the top of a mountain a difference of about 1/2 of one percent in the reading of a scale marked alongside the spring might be detected. But if a balance be carried from one such locality to another, no variations are observed in the masses measured by it. Hence it may be seen that only the force is changed.
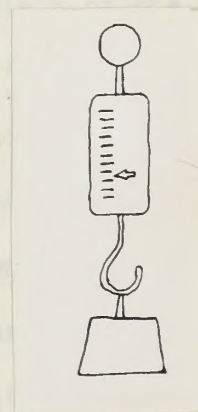
The unit of energy in the gravitational or elastic forms becomes the foot-pound (meaning feet times pounds), the pound being the unit of force. Balances and spring scales actually measure the force of gravity on a body, although they are commonly supposed to measure mass, that is, quantity of matter. In the later paragraph on Inertial Mass the important distinction

between the concepts of force and of mass will be emphasized.

Fundamental and Derived Quantities.

Competent authorities are of the opinion that all quantities in physics may be derived from five fundamental quantities. Three of these—mass, length and charge, have been introduced in the chapter on Structure of Matter, and the fourth, temperature, is studied in connection with thermometers and calorimeters.

The fifth fundamental concept is time. Everyone is conscious of the progress and duration of time, which is the interval between two events. It cannot be explained in words having any simpler significance than time itself. It goes always forward in human consciousness. Measurement of time is defined in terms of the rotation of the earth, a second being 1/86400 part of the mean solar day. Seconds, minutes and hours are usually measured by pendulums, by balance wheel clocks and watches, or by rotation in a field of force. The relative amount of time consumed by various processes is a familiar phenomenon. For example, a barrel full of water is emptied rapidly by running out through a hole, but a barrel full of molasses is emptied more slowly.

In mechanics, to which this chapter is limited, all quantities may be derived from three of the five fundamental ones, namely mass, length and time. The derivation of the units of force and of energy from these three is somewhat roundabout, and through several following paragraphs the necessary ideas will be built up to make this derivation.

Among readily derived quantities, it has already been shown that density is derived from mass and length. Velocity is a useful quantity which may be derived from length and time, and conveniently expressed in

feet per second. Often the motion of a body is such that the velocity is
first faster and then slower. But if the velocity is steady, (or if it is
irregular, the average velocity) it is computed by dividing the distance
in feet by the time in seconds. Letting v = velocity, s = distance and
t = time

$$v = \frac{s}{t}$$

Motion Due to Gravity.

The force of attraction of gravity is an important cause of motion.
For a thousand years before Galileo it was supposed that the heavier
an object was, the faster it fell. But in 1590 he released objects of
different masses simultaneously from the leaning tower of Pisa, and showed
that the heavier one and the lighter struck the ground nearly together. In
general, the speed of a falling object becomes faster and faster the further
it falls. However air friction, which is zero when there is no motion,
becomes greater and greater the faster the motion. When falling from a
sufficient height, a body reaches a limiting speed where the attractive
force of the earth urging it to greater speed is balanced by the resisting
friction of the air. In the case of fine rain drops this limiting speed
is quite low. For hail stones it is a higher speed. A demonstration is
often performed with a feather and a coin in a glass tube about four feet
long and two inches in diameter, closed at both ends, but provided with a
connection so that it can be exhausted with a vacuum pump. Then when the
tube is tipped from end to end, the feather and the coin are seen to fall
together. Unfortunately it is impossible to make precise measurements
with balls falling through the air, or rolling down grooves, because
friction can never be entirely eliminated, but in this immediate discussion
it will be assumed that friction may be neglected.

By dropping stones from points higher and higher up a tower or cliff, and measuring the time to hit bottom, it is found that a stone falls nearly --

    -16 feet during the first second

    -64 feet during the first two seconds

    -144 feet during the first three seconds

The striking fact about these figures is that the distance fallen equals the square of the number of seconds times the number of feet fallen during the first second. That is, simple algebraic relations exist between these values, as may be shown by tabulating them as follows.

Elapsed time seconds	Total distance fallen feet	Average time	Distance gained each second
0	0		
1	$16 = 16 \times 1^2$	0.5	$16 - 0 = 16$
2	$64 = 16 \times 2^2$	1.5	$64 - 16 = 48$
3	$144 = 16 \times 3^2$	2.5	$144 - 64 = 80$
4	$256 = 16 \times 4^2$	3.5	$256 - 144 = 112$
5	$400 = 16 \times 5^2$	4.5	$400 - 256 = 144$
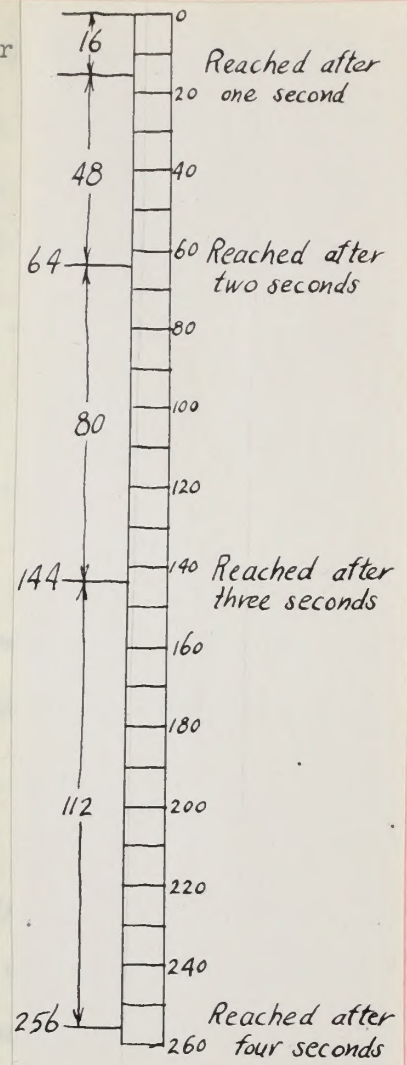
Using h = height in feet, t = time in seconds, and v = speed in feet per second, the second column gives $h = 16 t^2$, and the last gives $v = 32 t$, that is $16 = 32 \times 0.5$ and $48 = 16 \times 1.5$. By algebraically eliminating t in these two simultaneous equations, a useful relation may be obtained between v and h.

That is, squaring $v = 32t$

$$v^2 = 32 t \times 32 t \quad \text{or} \quad v^2 = 32 \times 32 t^2$$

But $t^2 = \frac{h}{16}$ from $h = 16 t^2$

Hence $v^2 = 32 \times 32 \frac{h}{16}$ or $v^2 = 64 h$ and $v = \sqrt{64h}$

By dropping a mass from points higher and higher
up a tower or cliff, and measuring the time to hit
bottom, it is found that a stone falls nearly --

—16 feet during the first second

—64 feet during the first two seconds

—144 feet during the first three seconds

The striking fact about these figures is that the
distance fallen equals the square of the number of
seconds times the number of feet fallen during the
first second. That is, simple algebraic relations
exist between these values, as may be shown by
tabulating them as follows.

Using h = height in feet, t = time in seconds, and v = speed in feet per
second, the second column gives h = 16 t², and the last gives v = 32 t,
that is 16 = 16 X 0.5 and 64 = 16 X 1.6. By algebraically eliminating
t in these two simultaneous equations, a useful relation may be obtained
between v and h.

Now if experiments be devised to measure the speed of an object sliding or rolling along an inclined path, it is found that, in whatever direction the path carries the object, the speed, disregarding friction, depends only on the vertical distance down from the point of rest from which the
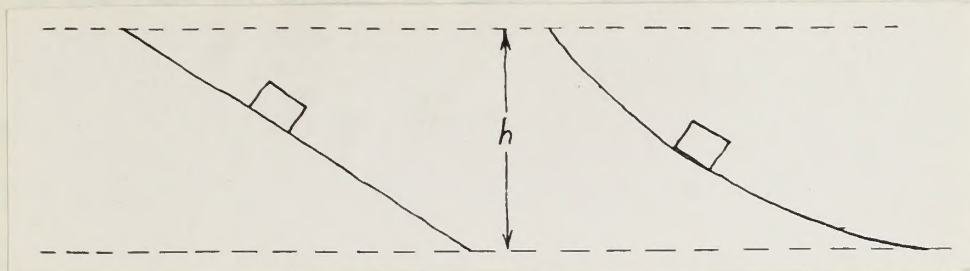
body starts. In other words, provided h be always measured vertically, the speed acquired by a body falling without friction through moderate heights is given by

$$v = \sqrt{64h} = 8\sqrt{h}$$

This does not depend on the quantity or kind of mass, nor on the shape of the path. This relationship is important because it is one of the relatively few experimentally observable facts on which the laws of mechanics are based.

Acceleration.

When the velocity of a body is changing it is being accelerated. If an automobile starts from rest, it has an acceleration until it reaches a steady speed. If it acquires a speed of 15 miles per hour in 5 seconds from the start, the acceleration is 15/5 = 3 miles per hour each second. In such a case the acceleration is not steady for any considerable length of time, for if it continued at the same rate for 30 seconds the speedometer would read 30 X 3 = 90 miles per hour. Acceleration is defined as the rate of change of velocity, that is, $a = \dfrac{v}{t}$

(It should be noted that v in this expression is a changing velocity, while v in the expression v = s/t is a uniform velocity). A better unit for acceleration is feet per second per second, rather than miles per hour per second. The above value of 3 miles per hour per second can be converted to 4.4 feet per second per second, because there are 5280 feet in a mile, 3600 seconds in an hour, and 3 X 5280/3600 = 4.4.

Returning to the case of a freely falling body, in the tabulation given above for the distances covered, significance was attached to the arithmetical difference between successive figures. If the values already obtained be repeated, and the method of differences be carried one column further, an interesting result occurs, for the difference is constantly 32.

Time seconds	Distance fallen	Distance gained each second	Velocity gained each second
0	0		
1	16	16	
2	64	48	48 - 16 = 32
3	144	80	80 - 48 = 32
4	256	112	112 - 80 = 32
5	400	144	144 - 112 = 32

Thus the acceleration of a falling body is 32 feet per second per second. This is called the acceleration of gravity.

The relations already obtained for a freely falling body are

$$h = 16 t^2 \qquad \text{and} \qquad v^2 = 64 h$$

Expressed in terms of the acceleration of gravity, g = 32, these are

$$h = \frac{1}{2} g t^2 \qquad \text{and} \qquad v^2 = 2 g h$$

Corresponding relations for any uniform acceleration, as for a train or for a ball rolling down an inclined groove, using the symbol s = distance covered are $\qquad s = \frac{1}{2} a t^2 \qquad \text{and} \qquad v^2 = 2 a s$

Impact.

   Experiments on impact, or the hitting of objects together, reveal

underlying principles of mechanics. Apparatus may be set up in a

Before impact   After impact   After impact   After inelastic
                      case one   case two   impact
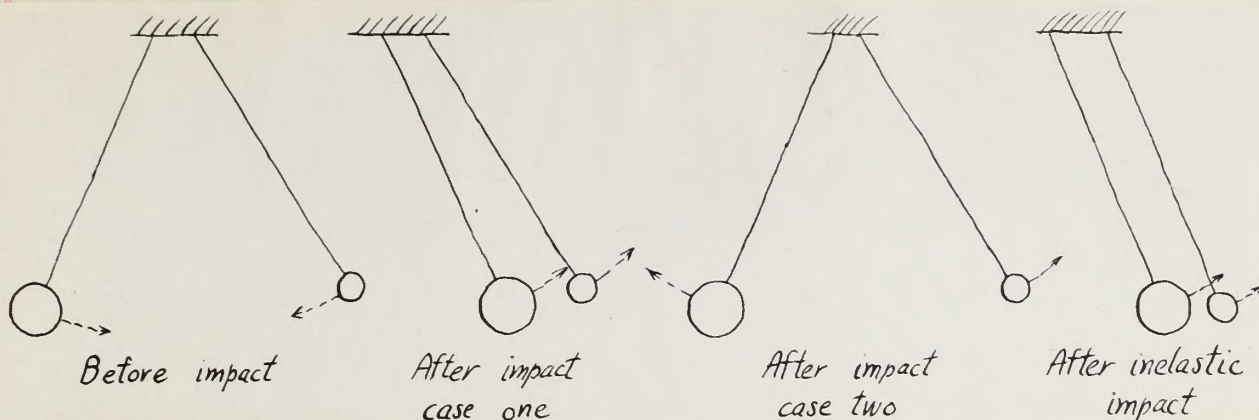
number of ways, for instance by suspending two balls of elastic material

such as steel or ivory from cords so that they may be drawn aside and

released to swing and hit each other. Depending on their relative masses,

and the relative heights from which they are released, the balls after

impact may both swing in the same direction (case one in the diagram), or

in opposite directions (case two). If the balls are of inelastic material,

they move together after impact.

   Measurements are somewhat simpler if the balls be rolled
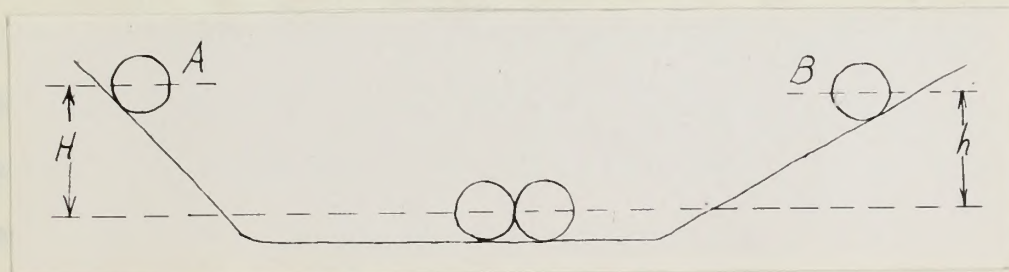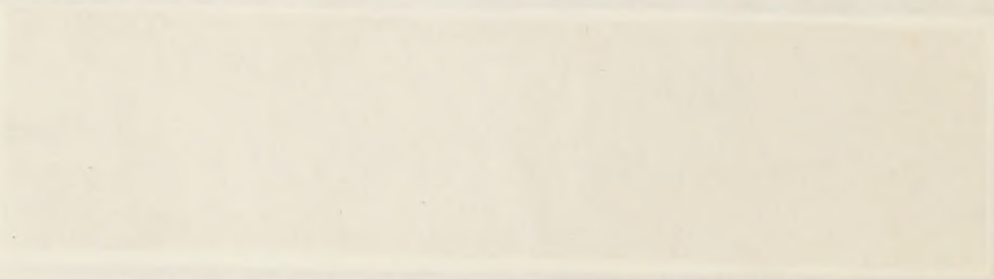
down a grooved track of the shape shown, with inclines at each side and a

horizontal portion between. Then, as previously mentioned, the velocity

of a ball after rolling down to the center portion may be readily computed,

using the height h (in feet) from which it starts, that is, $v = 8\sqrt{h}$ feet

per second.

Consider the case of two balls of lead or clay, that is, of inelastic material, having the same diameter but of different masses. When released from each side, they continue moving together after impact in one direction or the opposite. But by trial it is found that pairs of points, such as A and B, may be selected such that, if the balls be released from these points, they bring each other to rest when they strike.

By the time Newton announced his laws of motion, it had been learned that such experiments may be formulated by defining a quantity called momentum as the product of the mass of a moving body by its velocity. When impact brings two balls to rest, if M and V are the mass and velocity of one, m and v are the mass and velocity of the other, and H and h are the heights from which they start, then the experimental measurements show that

$$M\sqrt{H} = m\sqrt{h}$$

But using the relations $V = 8\sqrt{H}$ and $v = 8\sqrt{h}$, the substitution can be made that $\sqrt{H} = \dfrac{V}{8}$ and $\sqrt{h} = \dfrac{v}{8}$ from which $\dfrac{MV}{8} = \dfrac{mv}{8}$

Hence $\quad MV = mv$

For most cases of impact of two balls, such as rolling down the groove shown in the diagram, both balls will be moving after impact. Just as the velocity of a ball before impact may be measured by the height from which it starts, so the velocity after impact may be measured by the height up the incline to which it rebounds. Such measurements show that the sum of the momentums before impact equals * the sum of the momentums after. This is an instance of what is called conservation of momentum.

---

* It should be realized that momentum is positive in one direction, let it be to the right, and negative in the opposite direction, to the left.

Kinetic Energy.

It is found that the concept of momentum is sufficient to explain impact of inelastic bodies. But Huygens in 1699 published a study showing that during impact of highly elastic bodies another quantity besides momentum (m v) is involved. This additional quantity he expressed as (m v^2), and it became one of the earliest notions of what is now called kinetic energy and written ($\frac{1}{2}$ m v^2). The one-half was not put into the expression for more than a century, because an equation between the energy before impact and the energy after impact balances without the one-half on both sides.

Just as momentum is defined as mass times velocity, so kinetic energy may be defined as momentum times velocity. Now a body cannot pass instantaneously from a state of rest to a state of motion, time being required while it acquires velocity, (even though during impact this interval of time may be very brief). Therefore during a change from rest to motion the average momentum is one-half the final momentum. When this is multiplied by velocity the expression for kinetic energy becomes

$$U = \frac{1}{2} M V^2$$

A convenient example of the acquiring of kinetic energy by a mass is a body falling without friction, for the gravitational energy due to its elevated position is converted into kinetic energy of motion. Now within moderate heights above sea level, difference in gravitational energy for a given body depends only on difference in its elevation from one position to another, and it has already been shown that the square of velocity likewise depends only on difference in elevation. As already shown, gravitational energy equals force times difference in elevation. The

relation for energy conversion from gravitational to kinetic energy becomes

$$F h = \frac{M v^2}{2}$$

Since the unit for gravitational energy is the foot-pound (the pound being a unit of force) the unit for kinetic energy may also be the foot-pound. In general, for any force due to a conversion from kinetic energy, whether the body is moving vertically or in any other direction

$$F s = U \qquad \text{or} \qquad F = \frac{U}{s}$$

Hence force may be defined as the space rate of change of energy.

Since velocity is derived from length and time, the derivations have now been made for energy and for force in terms of the three fundamental quantities, mass, length and time, as promised several paragraphs back.

Inertial Mass.

If algebraic substitution of $v^2 = 2a h$ be made in the relation just given between kinetic energy and force, there results

$$F h = \frac{M v^2}{2} = \frac{M(2a h)}{2}$$

Cancelling out h gives an important relation between force, mass and acceleration

$$F = M a$$

When applied to a freely falling body so that a = 32 feet per second per second, this gives F = M x 32. The force exerted by gravity is measurable, and the term used in measuring it is 'pound'. But a force of one pound is not the same thing as a mass of one pound, as can be seen in the above equation, which does not balance when F = 1 and M = 1 because a = 32. The word 'weight' is correctly used to mean the force of gravity on a body. Of course a body appearing to weigh one pound on our earth would appear on a spring scale to weigh much less than one pound on the planet Mars.

The use of the word 'pound' as a unit both of force and of mass in

studying mechanics is the source of considerable confusion, to avoid

which no ideal way has yet been devised. The source of the difficulty is

the two aspects of mass, gravitational and inertial, which are exactly

proportional to each other according to all known experimental evidence.

A body of matter stores energy in the gravitational field, it also acquires

kinetic energy when set in motion. Inertia is the property of matter

which resists any change in its state either of rest or of motion in a

straight line. Probably the least undesirable way out of the confusion over

the two 'pounds' in U. S. practice is the use of the familiar unit 'pound'

for the more subtle concept of force, and the use of 'slug' for the unit

of mass in any problem involving inertia, the slug being 32 pounds (more

precisely 32.17 pounds). Then in the relation $F = M a$ when $F = 1$ pound,

$M = 0.031$ slug, and $a = 32$, the equation balances.

A unit of momentum is the slug-foot per second.

Principles -- Energy and the Concepts of Mechanics

Every variation in the properties of matter is due to an energy change.

Physical and chemical changes are examples.

Energy exists in several forms, such as gravitational, elastic, kinetic,

chemical, radiant and thermal. In numerous ways it may be converted

from one form to another, but there is never any net gain or loss.

(Under special conditions mass and energy are mutually convertible).

Due to orderly shape and relative position, attractions such as gravitation-

al and elastic are exhibited between neighboring bodies. These are

attributed to the storage of energy in fields.

Energy stored in fields tends spontaneously to convert into forms asso-

ciated with orderly motion, such as kinetic and magnetic energy. In

turn, these tend spontaneously to convert into a form representing

disordered motion, that is, into heat.

Force is a phenomenon due to attraction in a field of energy, or to con-

version of energy from a more highly ordered to a less highly

ordered form.

Energy stored in the gravitational field is measured by force times height.

Forces may be compared and measured by gravitational or elastic attraction.

All quantities in mechanics may be derived from three indefinable ones:

mass, length and time. Density and velocity are examples of derived

quantities.

The velocity acquired by a body falling without friction depends only on

the drop in elevation down from rest, not on the size or kind of mat-

ter, nor on the path if, for instance, it is a ball rolling down a

groove.

Acceleration is the rate of change of velocity.

The momentum of a body is the product of its mass times its velocity.

 During the impact of two bodies the sum of their momentums is

 conserved.

The kinetic energy of a body equals one half the product of its mass and

 the square of its velocity.

A measure of force is the rate of decrease of energy with distance.

The mass of a body is invariable, but the force of gravity on it varies

 from one locality to another.

Test -- Energy and the Concepts of Mechanics

MARK in the right margin the letter corresponding to each item in the
left column. Use each letter once and only once, and leave blanks
after the two surplus words. The first one has been done as a sample.

Ratio of mass to volume (A)

Self evident or necessarily true (B)

Occurring at the same time (C)

Without duration of time (D)

Degree of skill in measurement (E)

Amount of some quantity measured per
unit of time (F)

Moving in a straight line (G)

One dimensional (H)

Capable of having a succession of values (I)

Having only a fixed value (J)

constant	( )
precision	( )
linear	( )
component	( )
density	(A)
axiomatic	( )
instantaneous	( )
inverse	( )
rectilinear	( )
simultaneous	( )
rate	( )
variable	( )

* * * * * * * * *

If the statement is correct, write 'true' on the line at the right. If it
is incorrect, write the term that must be substituted for the under-
lined term, to make the statement correct. The first one has been
done as a sample.

Mercury is a solid at ordinary temperatures.   liquid

A rod one-half inch square and one foot long contains
three cubic inches.   _____

If the density of zinc is one-quarter pound per cubic inch,
a zinc rod one inch square and 10 inches long has a
mass of forty pounds.   _____

A body cannot have kinetic energy and gravitational energy
at the same time.   _____

Write in the right margin the letter corresponding to each term in the left column. Use each letter once and only once, and leave blanks after the two surplus words. The first one has been done as a sample.

( ) constant

( ) precision

( ) linear

( ) permanent

(A) density

( ) axiomatic

( ) instantaneous

( ) inverse

( ) rectilinear

( ) simultaneous

( ) rate

( ) variable

(A) Ratio of mass to volume

(B) Self evident or necessarily true

(C) Occurring at the same time

(D) Without duration of time

(E) Degree of skill in measurement

(F) Amount of some quantity measured per unit of time

(G) Having in a straight line

(H) One dimensional

(I) Capable of having a succession of values

(J) Having only a fixed value

*   *   *   *   *   *   *   *

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A body cannot have kinetic energy and gravitational energy at the same time.   _____

Ordered forms of energy tend <u>spontaneously</u> to convert to
  disordered forms.

A ball thrown upward <u>gains</u> kinetic energy while rising.

Some properties of a <u>group of bodies</u> depend on shape and
  relative position.

A unit of volume is a length <u>squared</u>.

Gravitational energy converts into heat energy only by
  way of <u>kinetic</u> energy.

<u>Work</u> is energy during a process of conversion from one
  form to another.

The <u>power</u> acquired by a body falling without friction
  depends only on the distance measured vertically down
  from rest.

The foot-pound per second is a unit of <u>speed</u>.

A unit of tension is the <u>pound</u>.

Power equals energy <u>divided</u> by speed.

A freely falling body falls <u>three</u> times as far during
  three seconds from rest, as during one second.

Doubling the speed of a body <u>quadruples</u> its kinetic energy.

I<u>f</u> a machine could be entirely frictionless, its output
  would equal its <u>efficiency</u>.

The moment arm of a force is <u>parallel</u> to the force.

Force equals the rate of change of energy with <u>elapsed time</u>.

A rocket ship is propelled <u>more</u> readily in empty space
  than in the earth's atmosphere.

        *   *   *   *   *   *   *   *   *   *

Each statement is followed by various ways of completing it, only one of
which is correct. Mark x in front of the correct way.

Of the following quantities, the one which is considered fundamental,
rather than derived, is -- ( ) density ( ) length ( ) speed
( ) elasticity.

The ounce and ton are units of -- ( ) density ( ) mass ( ) energy ( ) speed.

Of the following, the term which is a unit of measurement is -- ( ) kinetic
( ) crystalline ( ) hour ( ) blue ( ) malleable.

The density of water in the metric system is -- ( ) 14.7 ( ) 62.4
( ) 1.0   ( ) 76.

Of two cubes of the same weight, but made of different materials, the
smaller in volume has the greater -- ( ) mass ( ) density ( ) length
( ) malleability.

Of two objects which are equivalent when placed one in each pan of a
balance, the smaller in volume has the greatest -- ( ) mass
( ) surface area ( ) density ( ) pressure.

A rectangular block Y is 4 inch x 4 inch x 1/2 inch thick and weighs
6 pounds. Another rectangular block Z of the same material is 2
inch x 2 inch x one inch thick. Then -- ( ) the volume of Y is
4 cubic inches ( ) the density of Y is 0.75 pounds per cubic inch
( ) the block Z weighs 6 pounds ( ) the density of Z is o.375 pounds
per cubic inch.

The most elastic of the following is -- ( ) a copper wire ( ) an ivory
billiard ball ( ) an archery bow ( ) an inner tube for a tire.

The use of the spring scale for weighing is an application of the law or
principle of -- ( ) Boyle ( ) Archimedes ( ) Pascal ( ) Hooke.

Elastic energy is possessed by -- ( ) a wound clock spring ( ) a swinging
pendulum ( ) a moving automobile ( ) the moon.

The form of energy associated with a body at rest because of its elevated
position is -- ( ) gravitational ( ) elastic ( ) kinetic
( ) chemical ( ) heat.

The principal reason that the weight of an object indicated by a spring
scale is not just the same on a mountain as at sea level is a dif-
ference in ( ) atmospheric pressure ( ) distance from the center of
the earth ( ) centrifugal force ( ) the mass of the object.

By carrying an object from one locality to another it is impossible to
change -- ( ) its mass ( ) the force of gravity on it ( ) the speed ac-
quired while falling one second from rest ( ) the time interval
required to fall 100 feet from rest.

A cannon ball attracts the whole earth -- ( ) just as much as the earth
attracts it ( ) almost but not quite as much as the earth attracts
it ( ) about half as much as the earth attracts it ( ) not at all.

Neglecting air friction, the speed with which a body must be projected
upward to rise to a given height, in comparison with the speed it
would acquire in falling through the same height, starting from
rest is -- ( ) the same ( ) half or less ( ) twice or more
( ) somewhat more but not twice.

While a stone is falling through the air -- ( ) kinetic energy is
proportional to speed ( ) speed is proportional to the distance
fallen ( ) the force of gravity decreases ( ) gravitational energy
decreases.

While a stone is falling through the air there is an increase in ( ) its
acceleration ( ) its gravitational energy ( ) its velocity ( ) the
force with which it is attracted to the earth.

Moving with uniform acceleration and starting from rest, a train travels
1000 feet during the first minute. During the first two minutes the
total distance in feet will be -- ( ) 1414 ( ) 2000 ( ) 3000
( ) 4000.

For a body to have an acceleration of 30 feet per second per second means
that the body ( ) is falling freely ( ) at the end of each second
is moving 30 feet per second faster than at the beginning of that
second ( ) has moved 30 feet from the beginning of any one second to
the end of that same second ( ) has a speed of 30 feet per second.

Acceleration is the rate of change with elapsed time of -- ( ) force
( ) distance ( ) velocity ( ) momentum.

If a body has motion with constant rectilinear acceleration, the distance
traveled from rest varies -- ( ) directly as the time ( ) inversely
as the time ( ) directly as the square of the time ( ) none of these
answers.

If the figures in the tabulation are the units of distance travelled by a
ball rolling down an inclined groove during the first second from rest,
and during successive intervals of one second of time, the case which
represents uniformly accelerated motion is --

	first second	second second	third second	fourth second
( ) case A	2	4	6	8
( ) case B	2	6	10	14
( ) case C	2	4	8	16
( ) case D	2	4	8	12

Rate of doing work with elapsed time is known as -- ( ) acceleration
( ) kinetic energy ( ) power ( ) efficiency

The name given to the opposition a body meets in rubbing across another is--

( ) efficiency ( ) power ( ) friction ( ) moment.

If the efficiency of a jack is 30 percent, the amount of energy in foot-
pounds which must be put in to raise a 3000-pound automobile 2 feet
is -- ( ) 1800   ( ) 4200   ( ) 8571   ( ) 20,000.

Most processes of conversion of energy are less than 100 percent efficient
because some energy goes into the form called -- ( ) gravitational
( ) thermal ( ) elastic ( ) chemical.

It is easier to lift a heavy weight with a block and tackle than without
because -- ( ) you may pull down on the rope ( ) there is little
friction in the pulleys ( ) the force exerted acts through a greater
distance than the weight lifted ( ) the rope is flexible and bends
around the pulleys.

By its length and inclination, a line with an arrow may be used to represent
on paper -- ( ) volume ( ) velocity ( ) mass ( ) energy.

Two boys pull unequally on opposite ends of a rope. The resultant force
may be represented on paper by -- ( ) the diagonal of a parallelogram
( ) the hypotenuse of a triangle ( ) the greater of the two forces
( ) the difference between the two forces.

It is impossible for the resultant of two forces to be -- ( ) less than
either of them ( ) less than their difference ( ) more than either
of them ( ) more than their sum.

If there is an angle of 90° between two forces acting at a point, one of
10 pounds and the other of 20 pounds, the resultant is -- ( ) 17.3
pounds ( ) between 10 and 17.2 pounds ( ) between 17.4 and 30
pounds ( ) more than 30 pounds.

A 150-pound sign painter sits on a sling supported by a single overhead
pulley. Neglecting friction and the weight of the sling, to pull
himself higher, he must exert a force in pounds on the free end of
the rope of-- ( ) 150   ( ) between 150 and 300   ( ) more than 300.

In the relation $U = 1/2 M v^{2}$ ( ) U is directly proportional to v ( ) U is
inversely proportional to M ( ) M is directly proportional to the
square of v ( ) U is directly proportional to M.

Gravitational attraction determines for a body its -- ( ) mass ( ) weight
( ) kinetic energy ( ) momentum.

A revolving fly wheel stores -- ( ) energy ( ) power ( ) force
( ) acceleration.

If the brakes on your automobile will retard it to a stop in 20 feet from
20 miles per hour, the distance in feet required to stop from 60 miles
per hour is -- ( ) 60   ( ) 120   ( ) 150   ( ) 180.

Driving the head on a hammer by striking a blow on the opposite end of the handle is an example of -- ( ) gravitation ( ) inertia ( ) centrifugal force ( ) power.

If a spring scale suspended from the ceiling of an elevator registers the weight of a 20-pound object as 18 pounds, it may be inferred that the elevator is -- ( ) ascending with uniform velocity ( ) starting to ascend with upward acceleration ( ) ascending but slower and slower to stop ( ) descending with uniform velocity.

In which of the following cases is the underlined body acted on by just three forces -- ( ) a 3-legged <u>table</u> standing on the floor ( ) a heavy metal <u>ring</u> supported by a <u>rope</u> stretched through it ( ) a <u>weight</u> hanging from a hook ( ) a <u>block</u> sliding on a frictionless inclined plane.

Given a body resting on a rough plane inclined at 20° with the horizontal. If the inclination be increased to 40°, the component of the weight of the body perpendicular to the plane is -- ( ) doubled ( ) increased but not doubled ( ) exactly halved ( ) decreased but not exactly halved.

A rocket starts upward with an acceleration of 16 feet per second per second. A spring scale inside the rocket supporting a 32-pound body (one slug) will read in pounds -- ( ) zero ( ) 2 ( ) 16 ( ) 48 ( ) none of these answers.

Two football players charge directly at each other and both are stopped by the collision. The mass of one is 200 pounds and he is moving at 8 feet per second. If the mass of the other player is 160 pounds he is moving in feet per second at ( ) 5 ( ) 6.4 ( ) 10 ( ) 45.

CHAPTER THREE
DIRECT-CURRENT ELECTRICITY

The Dielectric Field.

Reviewing paragraphs in previous chapters,--electric charge is one of five fundamental concepts from which all other necessary quantities in physics may be derived, the other four being mass, length, time and temperature. It has been pointed out that, under some conditions, if two dissimilar bodies are brought into intimate contact and then separated, they are found to be charged. A distinction may be observed that one is charged oppositely to the other, so that one kind of charge is called positive and the other negative. The explanation made for the charged state of a body is that its atoms do not have their normal number of electrons. The charge on the electron is assumed to be negative, hence the charge on a body due to a deficiency of electrons is designated positive, and that due to an excess of electrons, negative.

Just as in the case of gravitation, the attraction due to charges is attributed to a field of energy. In this case it is called a dielectric field, and again it depends on size, shape and relative position. A distinction is that the gravitational field never repels, though the dielectric field may either attract or repel. While a gravitational field is a property of matter due to its mass, a dielectric field is a property of matter due to its charge.

A characteristic feature of a dielectric field may be shown with needle-shaped bits of certain materials. (Bits 1/4 to 1/2 inch long cut from cork are suitable, or bits of glass fibre or of silk thread). When a vulcanite rod which has been rubbed with fur is touched to a heap of such bits, they cling to it in a manner suggesting a pattern of curved lines.

Especially if the end of the vulcanite rod be brought near the end of a

Vulcanite   Glass
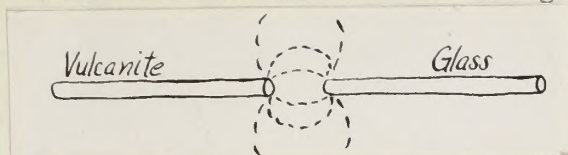
glass rod which has been rubbed with silk, the bits may be observed to form

a pattern as shown. Such lines are called lines of dielectric flux.

It is well known that a similar effect, with what are known as magnetic

lines of flux, is readily demonstrated by laying a piece of stiff paper

horizontally over a magnet and sprinkling iron filings on the paper. The

filings exhibit a pattern of lines

as shown dotted in the diagram.
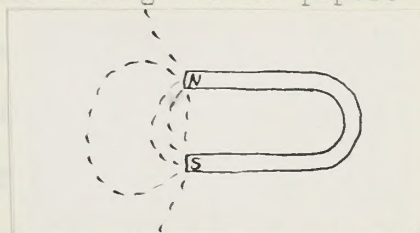
Conductors and Insulators.

Metals exhibit a characteristic behavior in relation to electric

charges, as may be shown in a variety of simple ways. Let two small balls

of dried corn cob or balsa be covered with tin foil and suspended from a

horizontal rod by silk threads. If one

is charged positively by being touched

with a glass rod which has been rubbed

with silk, and the other is charged nega-

tively by being touched with a vulcanite

rod which has been rubbed with fur, they

will attract each other. A piece of

Silk threads

Discharge
tongs

Cellophane

cellophane may be held between the two balls so that they cannot quite

touch. Now let a piece of copper wire be bent into the shape of tongs and

wrapped around a glass rod for a handle as shown, and if the wire be

touched across the two balls they lose their charges and no longer attract

each other.
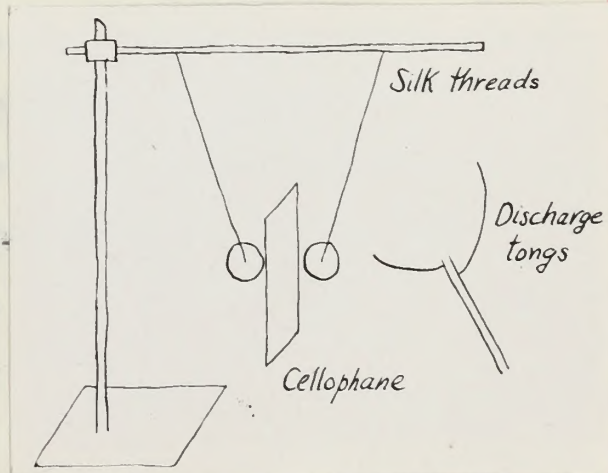
Thus it may be seen that charges move freely along metals but not glass, vulcanite or silk. Metals are called conductors, and materials which resist the motion of charges are called dielectrics (insulators). Some chemical solutions are conductors of charges, while air, wood, and paper if dry, are dielectrics, as well as many translucent bodies. But the terms 'conductor' and 'insulator' are relative, for to some extent all bodies permit the flow of charges, and all obstruct it.

Capacitors.

Charges may be moved from place to place and from one body to another in various instructive ways. For instance, given a pan filled with wax or similar insulating material, if the wax be rubbed with a cloth, it acquires a charge, let it be negative. Now if a metal disk supported by an insulating handle be brought near, the lower surface of the disk becomes positively charged due to the attraction of unlike charges, leaving the upper surface negatively charged. Next, if the upper surface of the disk be touched with the finger, its negative charge escapes into the finger. After withdrawing the finger, the metal disk with its entirely positive charge may be carried away from the wax.
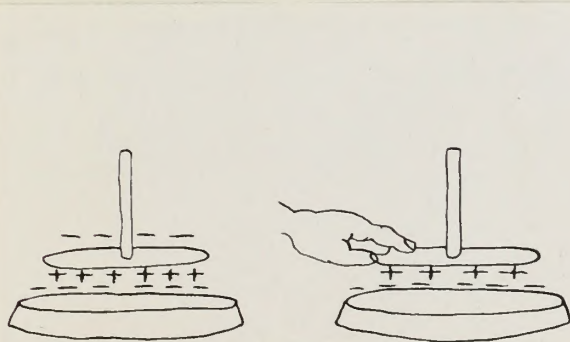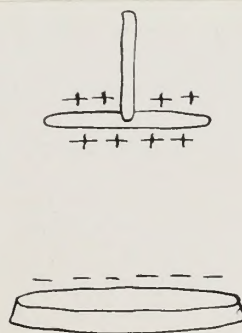
Electrophorus   Leyden jar

energy stored in a dielectric field between them. A device designed to

store energy in this manner is called a capacitor*. Various forms of capacitors are made, in any of which there are two metal surfaces separated by an insulating material. An example, called a Leyden jar, consists of a glass jar with inner and outer coatings of tin foil or sheet brass. A metal knob or hook is connected to the inner coating.

The Leyden jar may be charged by touching the hook with the charged metal disk just described. Then the whole process may be repeated by bringing the metal disk near the wax, momentarily touching the upper surface of the disk with the finger, and again moving the disk against the hook on the Leyden jar, thus adding to the charge on the jar.

This may be compared with pumping water into a standpipe. With each stroke of the pump equal amounts of water are raised, and the energy stored in the gravitational field increases to correspond with the higher ele- vation reached by the water surface in the standpipe.

So with the Leyden jar, with each repeti- tion of the process with the wax and the disk, equal amounts of charge are added to the jar and the dielectric energy stored increases to correspond with the higher voltage. This may be expressed in symbols

$$U = q E \qquad \text{joules}$$

where U = energy, q = charge in coulombs and E = voltage-drop. This re- lation will appear again after a few paragraphs, with more explanation

* Between the synonyms 'condenser' and 'capacitor', the latter seems pre- ferable, because it fits so well with the terms used in more advanced texts, capacitance, capacitivity, and corresponds with resistor, resistance and resistivity. Moreover 'condenser' is used in other meanings with steam turbines and with optical lens systems.

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of the meaning of voltage.

In the gravitational field a mass tends to fall through a drop in
height, and in the dielectric field a charge tends to move through a drop
in voltage. When the disk is touched with the finger the voltage of the
disk is higher than that of the human body, so the charge moves into the
finger. Because the human body is larger than the disk, a moderate charge
hardly raises its voltage.

Voltaic Cells.

A discussion of chemical action seems the best approach to the measure-
ment of electrical and magnetic quantities, and the development of mathe-
matical relations permitting numerical calculations.

As an example of chemical action, if powdered zinc be placed in a
solution of copper sulfate the zinc dissolves, copper is precipitated,
and energy is liberated   and   the solution grows warm. Almost identical
behavior takes place in the cell used for telegraphy, but the energy libera-
ted appears as electricity. This cell consists of a piece of sheet copper

Sounder   Key   Cell
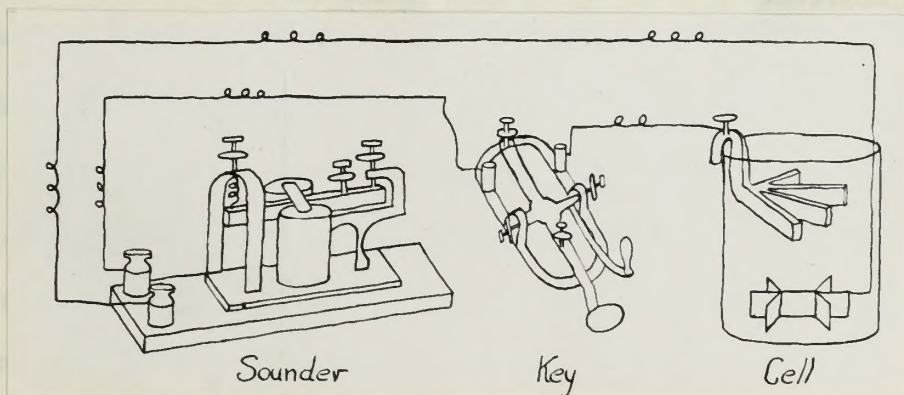
placed on edge in the bottom of a three-quart jar, and a piece of zinc,
usually cast as a crow-foot, hung over the wide brim. The jar is filled
with a solution of copper sulfate, but while in use zinc sulfate is
formed in the upper portion, and the difference in density maintains the

two solutions, one above the other. This is one example of a voltaic

cell. Let a wire be connected outside the cell as a circuit, for instance

from the copper through a telegraph key and sounder and back to the zinc,

and the zinc begins to dissolve, copper is deposited as before, but

energy is liberated in an electrical form which may be made evident by

such effects as operating the sounder.

In copper sulfate solution a copper ion having fewer electrons than

the normal number in a copper atom is chemically bonded with a sulfate

ion having spare electrons. (A copper ion is deficient by two electrons

because the chemical valence is two). An atom of zinc loses two electrons

thus becoming a zinc ion, and the two electrons wander into the wire

circuit. At the other end of the wire two compensating electrons wander

out of the wire and attach themselves to a copper ion thus making it a

copper atom and releasing the chemical bond with the sulfate ion. Mean-

while the zinc ion attaches itself to the sulfate ion, taking up the two

spare electrons, and forming a molecule of zinc sulfate.

For the study of its effects the electric circuit may be varied in

many ways. The flow of electrons constitutes a current in the wire. Any

number of voltaic cells may be connected together by metal wires into a

battery, which converts more energy from chemical to electrical than a

single cell. There is always some frictional resistance to the motion of

electrons along a wire, depending on its diameter and the kind of metal of

which it is made, hence more or less heat is developed in the wire. One of

Faraday's accomplishments was proving the identity of electricity as pro-

duced by the separation of two dissimilar materials with electricity as

produced by a voltaic cell. A capacitor may be charged by temporarily

connecting it across a battery.

two solutions, one above the other. This is one example of a voltaic cell. Let a wire be connected outside the cell as a _circuit_, for instance from the copper through a telegraph key and sounder and back to the zinc, and the zinc begins to dissolve, copper is deposited as before, but energy is liberated in an electrical form which may be made evident by such effects as operating the sounder.

In copper sulfate solution a copper ion having fewer electrons than the normal number in a copper atom is chemically bound with a sulfate ion having spare electrons. (A copper ion is deficient by two electrons because the chemical valence is two). An atom of zinc loses two electrons thus becoming a zinc ion, and the two electrons wander into the wire circuit. At the other end of the wire two compensating electrons wander out of the wire and attach themselves to a copper ion making it a copper atom and releasing the chemical bond with the sulfate ion. Meanwhile the zinc ion attaches itself to the sulfate ion, taking up the two spare electrons, and forming a molecule of zinc sulfate.

For the study of its effects the electric circuit may be varied in many ways. The flow of electrons constitutes a _current_ in the wire. Any number of voltaic cells may be connected together by metal wires into a battery, which converts more energy from chemical to electrical than a single cell. There is always some frictional resistance to the motion of electrons along a wire, depending on its diameter and the kind of metal of which it is made, hence more or less heat is developed in the wire. One of Faraday's accomplishments was proving the identity of electricity as produced by the separation of two dissimilar materials with electricity as produced by a voltaic cell. A capacitor may be charged by temporarily connecting it across a battery.

In general, any voltaic cell includes two different metals and a solution of an acid, base or salt. The chemical solution and one of the metals are gradually exhausted during the use of the cell. It has been discovered that all common metals may be listed in an activity series * such that the tendency to lose electrons is progressive throughout the series. Thus if any two metals be proposed for use in a voltaic cell, the one from which electrons will enter the wire circuit can be predicted. A dry cell is not really dry, but contains a moist paste of ammonium chloride with some manganese dioxide to reduce the tendency of hydrogen to collect. These chemicals are contained in a zinc can which forms one of the metals. Down through the center is a graphite post, which is used instead of a second metal. The top is sealed with a compound to prevent spilling, and the zinc is enclosed in a cardboard cover. A dry cell is a very convenient source of relatively small amounts of current, though the cost in terms of zinc used up is relatively high. In a storage battery, such as on an automobile, the chemical reaction is reversible and proceeds in one direction when the cells are delivering current, as when operating the starting mechanism, and in the other when current is delivered to the cells, as when the car is running.

Electrolytic Cells.

Under proper conditions an electric circuit may be completed through various chemical solutions. The diagram following shows three dry cells connected through a switch to two jars of conducting solution, and also to a coil of fine wire to show the liberation of heat. Suppose one jar

---

*For activity series, also called replacement series, or electromotive series, see any textbook of chemistry.

contains a solution of silver nitrate into which dip two separated

Battery of dry cells — Reversing switch — Anode Cathode Anode Cathode — Copper sulfate cell — Silver nitrate cell — Heating coil shown in a calorimeter — Thermometer
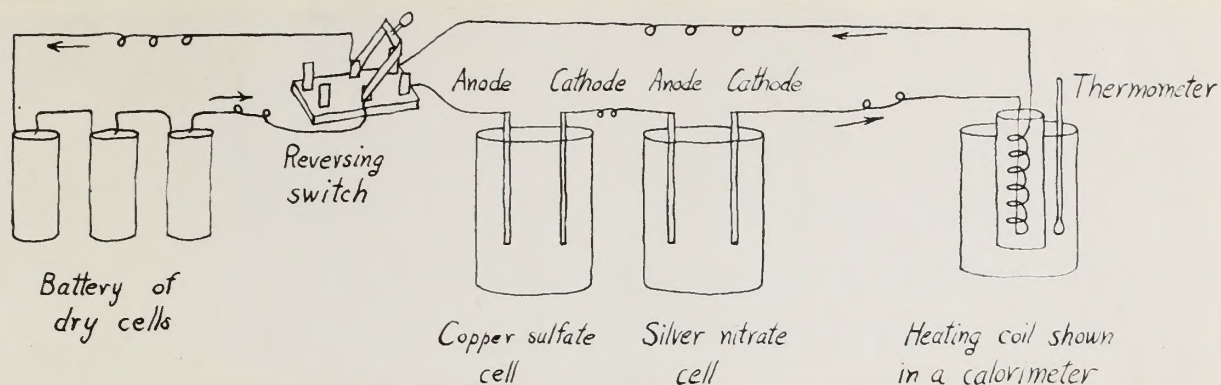
strips of silver, and the other jar contains a solution of copper sulfate
into which dip two bars of copper, with the wires connected as shown. A
jar such as one of these is known as an electrolytic cell, and each metal
strip is called an anode or a cathode, the cathode being the one through
which electrons enter the electrolytic cell from the wire circuit. Upon
completing the wire circuit it is found that silver begins to be removed
from one strip (the anode) and an equal amount deposited on the other in
the silver nitrate cell, and copper begins to be removed from the anode
and deposited on the cathode in the copper sulfate cell.

   Years ago, before the discovery of the electron, it became necessary
to agree on which way the arrow indicating current in a wire circuit should
be pointed, and the best clue was the deposition of metal in an electroly-
tic cell. The arrows in the diagram are in accordance with long-standing
custom for indicating what everyone calls 'current', although today it is
known that electrons (called negative charges) drift along the wire in
the opposite direction. Protons, that is elementary positive charges in
atoms, are not believed to be free to move. Although it may appear confusing
to always use the word 'current' and mark ∤ and - on terminals of voltaic

cells in the direction contrary to the real movement of electrons, actually
the reader will have no difficulty except in certain special topics such as
oxidation reactions in chemistry, or the behavior in radio tubes.

Michael Faraday experimentally observed that whenever current passes
from an anode to a cathode immersed in a conducting solution, a chemical
change occurs exactly in proportion to the charge of electricity which passes.
The amount of chemical change is measured by the mass of material released.
In a suitable electrolytic cell the amount of charge q passing through may
be defined as

$$q = \frac{43,770,000 \; m \; n}{w} = \frac{43,770,000 \; m}{j} \quad \text{coulombs,}$$

where m = pounds of metal deposited, w = its atomic weight, and n = its
valence. Values of j are: aluminum 9.03, copper 31.8, zinc 32.7, lead
103.5, silver 107.9. The constant 43,770,000 makes the equation agree
with the accepted value of the coulomb.

Steady Currents in Wires.

In principle the apparatus shown in the diagram of electrolytic cells
may be used to demonstrate several essential features of the electric cir-
cuit. All circuit effects start and stop with the closing and opening of
the switch, called 'making and breaking' the circuit. An electric current
flows only in a closed circuit and is a condition of the circuit as a
whole, that is, moving charges cannot accumulate at any point. (However, for
a moment current will pass into a capacitor).

The heating effect at the coil of wire takes place irrespective of
reversing the wire connections, yet the side of the electrolytic cell
at which metal is deposited is changed by reversing the wires. (Much
commercial energy today is developed as alternating current in which the

current rapidly reverses, but discussion of such topics must be postponed).

In the diagram the amount of heat liberated at the heating coil is found to be proportional to the amount of metal deposited in an electrolytic cell; in fact, the magnitude of one effect of current in part of a circuit is always proportional to other effects in other parts. For instance, if more voltaic cells be connected to supply more current, the heating effect is increased in the same proportion as the deposition of metal.

Current in amperes is the rate at which charge in coulombs passes a given point in a circuit per second. For steady currents

$$q = I\,t \text{ coulombs} \quad \text{or} \quad I = \frac{q}{t} \text{ amperes}$$

where t = time in seconds, and the unit of current I is called the ampere in honor of André Ampère. In accordance with $I = q/t$ and $q = 4377000m\ n/w$ an ampere deposits 2.47 pounds of silver from a silver nitrate solution in 100,000 seconds (nearly 28 hours), or o.001118 grams per second.

There are various important applications for electroplating, that is, the depositing of metal by current passing through a chemical solution. The silver on table knives and forks is put on an iron base by this method, as well as the chromium finish on automobile bumpers. Copper is refined by electrolysis. The economical production of aluminum metal and of chlorine gas is only by electrolytic methods.

The time interval required for effects to occur throughout a circuit after closing the metallic connections is so brief as to defy detection in many instances. While a wire is carrying electric current a flow of energy takes place accompanied by a motion of electrons along the wire, though their speed is only a few inches per second. This may be compared with the application of the air brakes on a long freight train. When the

engineer turns his valve, the change in pressure moves to the last car and applies the brakes long before any molecules of air move from one end of the train to the other.

Voltage-drop Along a Circuit.

A comparison may be drawn between the behavior of rain drops and the motion of charges along a wire. When a body is falling faster and faster it gains more and more kinetic energy while the gravitational field loses more and more energy. But with falling rain drops the kinetic energy is nearly constant because air friction absorbs in heat the loss of gravitational energy. The amount of gravitational energy converted into heat is proportional both to the amount of water falling, and to the difference in elevation.

So with a wire connected to a battery of voltaic cells, chemical energy from the cells is converted at least partly into heat liberated from the wire. (If the wire is wound on a magnet some energy may be converted mechanically by the force exerted by the magnet). The amount of energy converted is proportional both to the amount of charge which passes along the wire, and to the voltage-drop. Expressed in symbols this is the same relation which was mentioned a few paragraphs back

$$U = q E \quad \text{joules} \qquad \text{or} \qquad E = \frac{U}{q} \quad \text{volts.}$$

Voltage-drop, often called difference of potential, is a property of the portion of a circuit between two points. It is equal to the quotient of the energy converted in that portion of the circuit and the charge passing.

It is instructive to consider a circuit part of which is divided between two or more paths made of wires of various lengths or of different

metals. Then by inserting measuring
devices, not shown in the diagram, in the
several branches, it may be proved that
the current entering the joint A through
the wire from the battery equals the sum
of the currents leaving it through the
X, Y and Z branches. (The handiest means
for measuring volts or amperes depends on
the magnetic effect of current as will be described in the later paragraph
'Galvanometers'.) Thus at any junction in any circuit the algebraic sum of
the amperes entering and leaving is zero.

Moreover, measuring devices would show that the energy converted in
each branch in this diagram is proportional to the charge passing
through that branch

$$\frac{U_X}{q_X} = \frac{U_Y}{q_Y} = \frac{U_Z}{q_Z}$$

where U = energy converted in joules, q = charge passing in coulombs, and
the subscripts refer to the branches. Hence the voltage-drop from A to
B is the same by any of the three paths, for E = U/q. In general, the
voltage-drop between any two points in a divided circuit is the same,
regardless of the path.

Important relations are obtained by algebraic substitution between
U = q E and q = I t, namely

$$U = E\,I\,t \quad \text{joules} \quad \text{or} \quad \frac{U}{t} = E\,I \quad \text{watts}$$

Now energy divided by time is the quantity known as power. Electrical
power in watts equals volts times amperes. The watt is named for James
Watt (1736 - 1819) and the kilowatt is 1000 watts. Kilowatts multiplied
by hours is a unit of energy, the kilowatt-hour familiar to all household

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voltage-drop between any two points in a divided circuit is the same,
regardless of the path.

Important relations are obtained by algebraic substitution between
U = qE and q = It, namely

$$U = EIt \text{ joules or } P = \frac{U}{t} = EI \text{ watts}$$

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Watt (1736 - 1819) and the kilowatt is 1000 watts. Kilowatts multiplied
by hours is a unit of energy, the kilowatt-hour familiar to all household

purchasers of electricity. By the law of conservation of energy there are
fixed ratios between this and all other units of energy, that is, one

kilowatt-hour = 3,600,000 joules

= 2,655,000 foot-pounds

A set of Christmas tree lights often consists of eight bulbs connected
as shown. If a voltmeter be connected
across any one of the bulbs, it will be
found to read the same as across any o-
ther. Thus the voltage-drop across
the whole set is divided into eight
equal parts.

Resistance.

When current passes along a conductor, it may be proved experimentally
that heat is liberated, and the rate of liberation (power) divided by the
square of the current in amperes is a constant for any given wire. That
is, if the current is doubled the rate of heat liberation is quadrupled.
Expressed in symbols

$$\frac{P}{I^2} = R \qquad \text{ohms}$$

where P = power in watts and I = current in amperes. The property of a
wire represented by the quantity R is called its resistance, and between
different wires it is found that their resistances depend on the length,
the diameter, and the particular metal of which they are made (moreover
somewhat on the temperature). From the last two formulas

$$\text{power} = E I = I^2 R$$

Hence $E = I R$ volts.

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depends on the temperature). From the last two formulas

power = E I = I²R

Hence E = I R   volts.

This is known as Ohm's law, and the unit of resistance is called the ohm.
One ohm may be defined as the resistance which permits a current of one
ampere to flow with a voltage-drop of one volt. The law holds for any
part of a circuit, that is, if the resistance between any two points is
known, and the current, then their product is the voltage-drop between
those two points, but R and E must both be taken between the same two
definite points in the circuit.

It is sometimes helpful to compare
the flow of electricity along a wire
with the flow of water in a pipe. Am-
peres correspond to rate of flow in gal-
lons per second. Voltage-drop corresponds
to the loss in pressure in pounds per square
inch, for instance between the two gauges in the diagram. Ohms correspond
to frictional resistance.

For wires of any given metal at a given temperature, it is easily
shown that doubling the length of a wire doubles its resistance, or
halving the diameter of a round wire quadruples its resistance. These are
instances of the general law that the resistance of a conductor is directly
proportional to its length and inversely proportional to its cross sectional
area. But for the same size and length of wire the resistance of one
metal such as silver is not equal to that of another such as iron. There
is such great utility for the computation of resistance of round wires
that a formula for this proportion is adapted for them

$$R = \frac{\rho\,\ell}{d^2} \quad \text{ohms}$$

where ℓ = length of the wire in feet, d = its diameter in thousandths of
an inch (mils), and ρ = resistivity, a factor which varies for the

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$$R = \frac{\rho\,l}{d^2} \quad \text{ohms}$$

where l = length of the wire in feet, d = its diameter in thousandths of an inch (mils), and ρ = resistivity, a factor which varies for the

particular metal used.

The resistivities of some metals at 68° F are: silver 9.9, copper 10.4, aluminum 17.4, nickel 46.9, iron wire 73. Resistivity increases as temperature rises. For any of these metals multiply the stated value of resistivity by a coefficient of o.0022 to find the increase for every degree above 68° to about 200°.

Voltaic cells have internal resistance. For a cell delivering current

$$V = E - I R$$

where R = internal resistance, V = voltage-drop between terminals of the external circuit, and E = voltage of the cell on open circuit. The standard dry cell has an internal resistance of about o.075 ohm, and E = 1.5 to 1.6 volts.

The Magnetic Field.

If iron filings be scattered on a horizontal surface of wood or paper with a wire inserted through it, the filings may be observed to arrange themselves in a circular pattern around the wire when a sufficient current of electricity passes. From this point of view a magnetic field of energy is believed to exist around a current-carrying wire. The pattern formed in the filings indicates lines of magnetic flux. These lines always inter-link the electric circuit, and the number of linkages is readily increased by winding the wire in a coil.

A current produces a pattern in iron filings
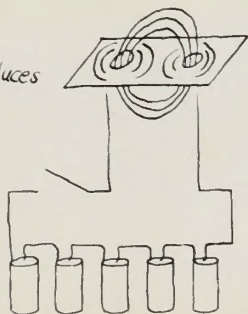
A discharging capacitor produces a pattern in iron filings

particular metal used.

The resistivities of some metals at 58° F are: silver 9.3, copper 10.4, aluminum 17.4, nickel 46.9, iron wire 78. Resistivity increases as temperature rises. For any of these metals multiply the stated value of resistivity by a coefficient of 0.0024 to find the increase for every degree above 68° to about 200°.

Voltaic cells have internal resistance. For a cell delivering current

$$V = E - IR$$

where R = internal resistance, V = voltage-drop between terminals of the external circuit, and E = voltage of the cell on open circuit. The standard dry cell has an internal resistance of about 0.075 ohm, and E = 1.5 to 1.6 volts.

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Furthermore if a capacitor be strongly charged and then discharged through a high resistance wire which passes through iron filings, an identical pattern effect is observed in the filings. Rowland (1848-1901) even showed experimentally that a magnetic field is produced by mechanically moving a charged body at high speed. For these reasons a magnetic field is attributed to the motion of electric charges.

In most materials a magnetic field disappears as soon as the current is cut off, but a bar or horseshoe of hardened steel, when magnetized by an electric current retains its magnetism after the circuit is broken, hence being known as a permanent magnet. A compass needle is such a magnet, with the end which turns toward the north called the north pole. Permanent magnetism is attributed to orientation of the atoms so that the electrons persistently revolve in parallel orbits. The lines of flux near a bar magnet are concentrated near the ends, hence the ends are known as poles. Experiments with two magnets show that like poles repel and unlike attract.

When a compass needle is placed near a current-carrying wire the needle is displaced in one direction if above the wire, and in the other direction
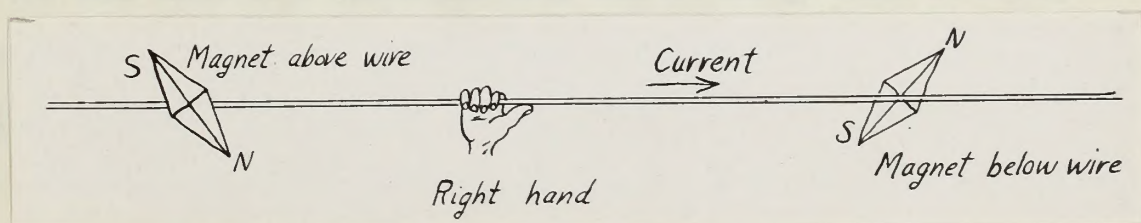
if below the wire. This shows that an arrow may be placed on a line of magnetic flux to indicate direction forward or backward. The customary way of pointing the arrow is as though the flux leaves a north pole and enters a south pole.

The magnetic fields of a coil with current flowing along it and of a permanent magnet are observed to attract in identical ways, hence the

properties of the field alone are essential
to describe the facts. The concept of
fields of energy, gravitational, dielectric
and magnetic, are hardly equalled in importance
by any other than the concept of matter itself.

Coil

Permanent magnet

In review of the picture of electrical phe-
nomena developed in the foregoing, upon connecting both a battery and a
coil in a wire circuit, chemical energy from the battery goes into
dielectric energy between the sides of the circuit, and in turn into
magnetic energy in a field interlinking the circuit. A steady state may
be reached in which chemical energy is continually going through these
conversions and is being dissipated as heat in the coil. The dielectric
field loses energy as fast as the magnetic field gains it, and in turn the
magnetic field loses it as fast as heat is dissipated in the coil. This
may be compared with an elevated tank of water representing energy stored
in the gravitational field. When water falls from a nozzle in the bottom
of the tank there is a conversion into kinetic energy which is dissipated
as heat when the water strikes the end of its fall.

Galvanometers.

The force between a permanent magnet and a coil of wire when current
flows along the wire supplies the handiest means for measuring the amount
of current flowing. There are various
devices of this sort, the commonest de-
sign being that shown in the diagram.
The alloy steel magnet is horseshoe shaped
and the coil is supported on a spindle car-
rying a pointer. The current is led into and

Pointer
Magnetic core
Moving coil
Bearing
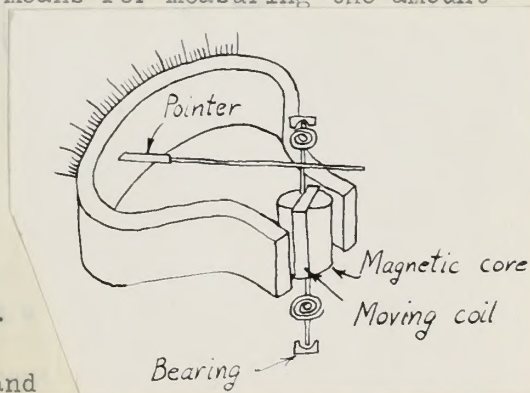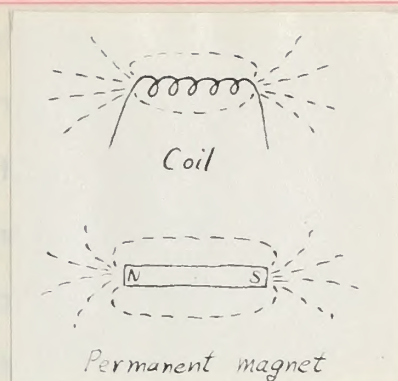
out of the coil through delicate spiral springs which hold the pointer to the left when no current is flowing. The greater the current flowing, the more is the movement of the pointer toward the right.

As a matter of practical design, the coil is made of very fine wire hence, without burning out, it will carry only small fractions of an ampere. But by connecting a low resistance shunt across the coil, the instrument is readily used to indicate large currents. For instance, if the resistance of the coil is 799 times the resistance of the shunt, then 1/800 of the total current will pass through the coil. The numbers on the dial are marked accordingly, so that the pointer reads the total amperes passing through both the coil and the shunt.

The same galvanometer instrument may be used with close approximation as a voltmeter by connecting a high resistance in series with the coil, and omitting the low resistance shunt.

The Magnetic Circuit.

Although lines of flux may not be taken apart or counted as the fibres in a cotton thread, it is necessary to introduce terms and symbols so that amounts of flux may be handled in numerical computations.

Consider a circular ring of wood or plastic wound with wire. While current is flowing along the wire there exists in the ring a magnetic flux which may be detected by iron filings or a compass needle at a break in the ring. Because magnetic lines of flux are continuous and endless, they form a circuit which may be treated in a manner somewhat similar to the electric circuit. The product of 'current times the number of linkages,'
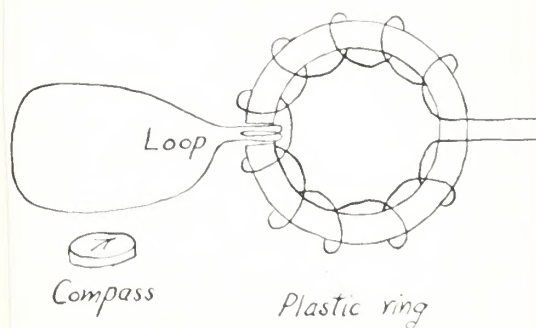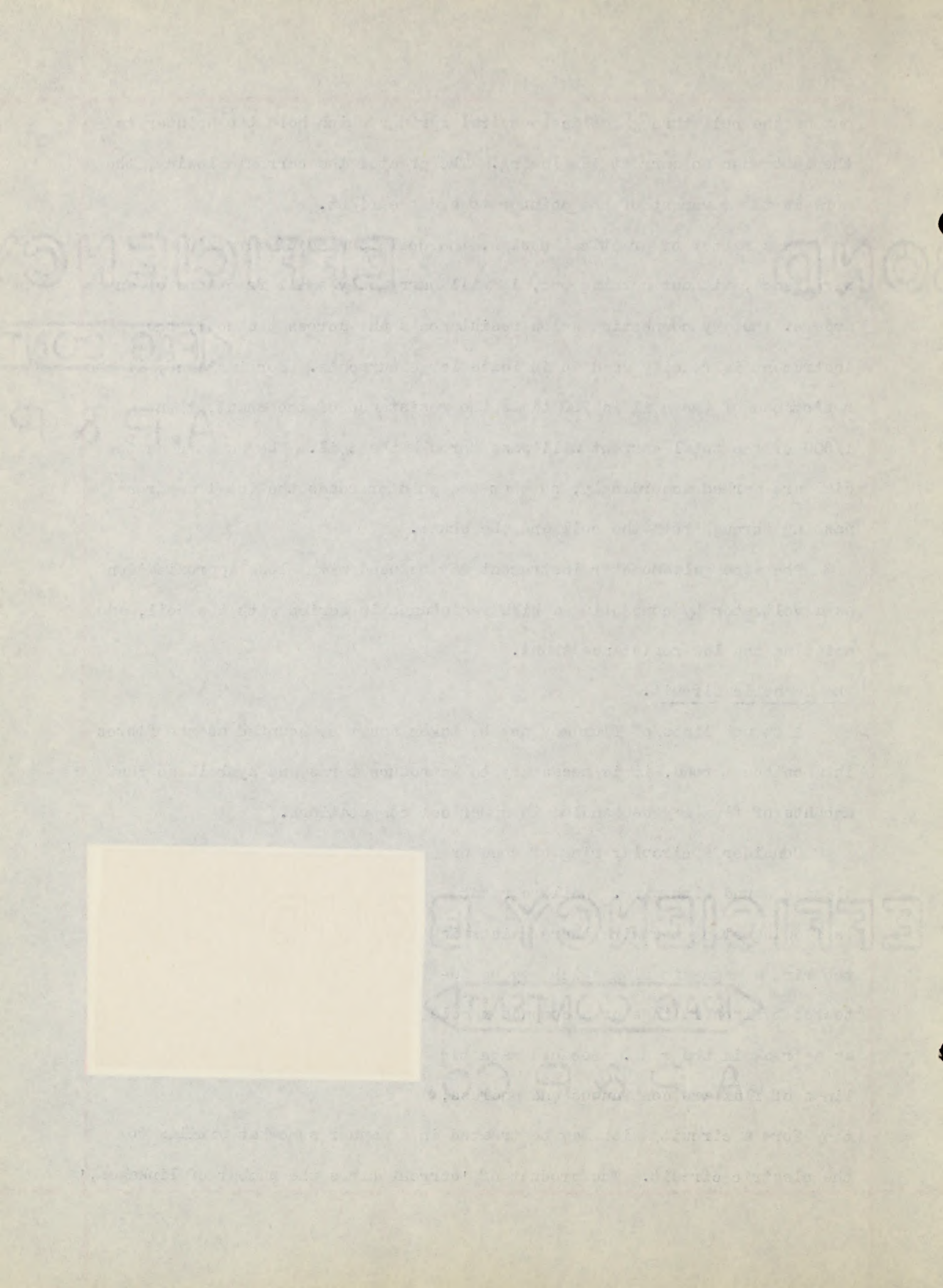
the unit being ampere-turns, is a measure of the potential difference in the magnetic field in much the same way as voltage-drop is a measure of potential in the dielectric field. Also for the magnetic circuit there is a quantity called reluctance which corresponds with resistance for the electric circuit. That is, just as for the electric circuit $I = E/R$, so for the magnetic circuit

$$\Phi = \frac{NI}{R} \quad \text{kilomaxwells}$$

where Φ = lines of magnet flux in kilomaxwells, N = number of turns, that is, the number of times the magnetic and electric circuits interlink each other, and R = reluctance. A name for the unit of reluctance is not usually attempted. For a magnetic circuit of simple geometrical shape, such as a ring, reluctance is proportional to the length of the circuit and inversely proportional to its cross sectional area

$$R = \frac{313\,\ell}{A}$$

where A = cross sectional area in square inches and ℓ = length of the path of magnetic lines in inches. The number 313 is the reluctivity * when the path of the magnetic circuit is through air or vacuum. This number makes the equations agree with the accepted value of the unit of magnetic flux, the kilomaxwell.

Reluctivity.

Just as various metals have different resistivities when used in wires

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*The permeability of iron is more commonly mentioned than its reluctivity. The value of one is the reciprocal of the value of the other, that is, if the permeability of a certain sample of iron is 2000, then its reluctivity is 1/2000. In these paragraphs reluctivity has been preferred to permeability because it lends itself to the simplest treatment in formulas. If the reader has difficulty in reconciling the properties of iron in the accompanying chart with those in other texts, it is probably because many authors express permeability relative to that of air = 1.00, instead of in such units as kilomaxwells per square inch/ampere-turn per inch.

Flux density ℬ, kilomaxwells per square inch

Reluctivity, ampere-turns per inch / kilomaxwell per square inch
Logarithmic scale
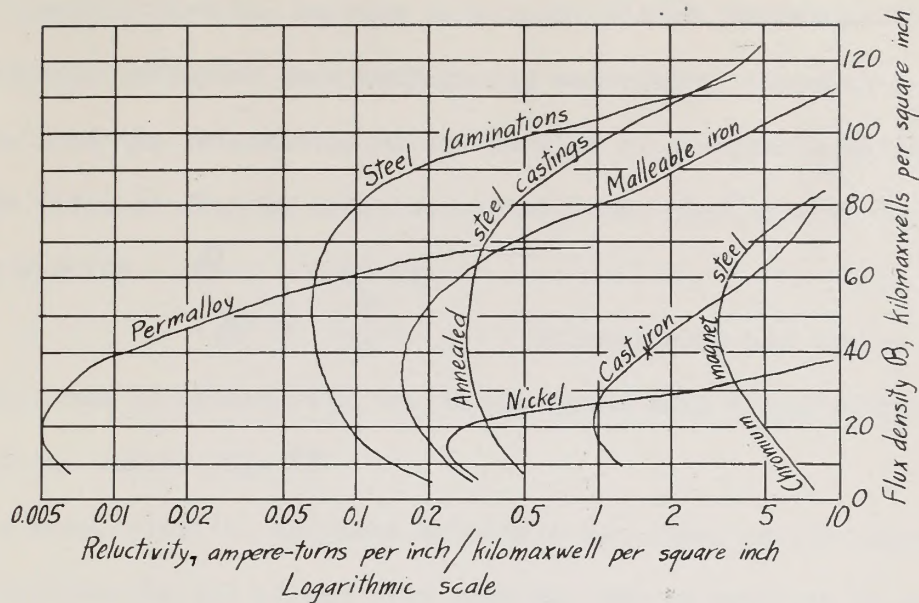
Problem: Let the pieces in the diagram be made of cast iron. The dimensions are: $AB = 8$ inch, $AC = 6$ inch, $DE = 2$ inch, the width of each part $= \frac{1}{2}$ inch, and the depth perpendicular to the diagram $= 1\frac{1}{2}$ inch. How many amperes are required to produce a flux of 30 kilomaxwells, if wound with 106 turns of wire. Assume no air gap, that is, CD is closed.

Solution : Area of cross section is $1.5 \times 0.5 = 0.75$ sq. in.

Flux density is $\frac{30}{0.75} = 40$ kilomaxwells per sq. in. On the chart $40 = ℬ$ intersects the cast iron curve at X, where the reluctivity is 1.55. The average length of the magnetic circuit along the dotted line is 30 inch.

$$ R = \frac{1.55\,l}{A} = \frac{1.55 \times 30}{0.75} = 62 $$

Substituting in $\Phi = \frac{NI}{R}$ gives $30 = \frac{106\,I}{62}$, from which $I = 17.5$ amperes

Now assume the same problem, but with two air gaps CD, each $\frac{1}{8}$ inch. For each gap

$$ R = \frac{313\,l}{A} = \frac{313 \times 0.125}{0.75} = 52 $$

The total reluctance is

$$ R_0 = R_1 + R_2 + R_3 = 52 + 52 + 62 = 166 $$

$$ \Phi = \frac{NI}{R} = 30 = \frac{106\,I}{166} $$

From which $I = 47$ amperes
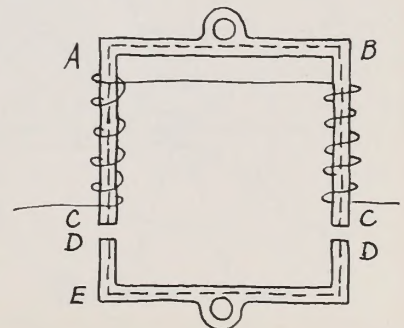
for an electric circuit, so some materials, called ferromagnetic, have reluctivities different from nonmagnetic materials. There is a complication however, that the reluctivity of any portion of a magnetic circuit varies with the ratio of flux to cross sectional area. Let this ratio be known as flux density B that is,

$$B = \frac{\Phi}{A}$$ kilomaxwells per square inch

The variations in reluctivity can be expressed only graphically, and are shown on the chart, page 89.

For wood, plastic, and most materials not shown on the chart the value for reluctivity is 313 at any flux density, and no material is known for which it is more than this (except bismuth and a few others for which it is slightly greater), hence there is no magnetic insulator. When a magnetic circuit includes varying materials or nonuniform cross sections arranged in series with each other (without abrupt change of section) the combined reluctance may be obtained from

$$R_0 = R_1 + R_2 + R_3 + \cdots$$

where R_0 = reluctivity of the whole magnetic circuit, and R_1 etc. = reluctivity of separate parts of the circuit.

Electromagnetic Induction.

Whenever a dielectric field is set up near a metal surface it seems that the ends of the lines of dielectric flux tend to move spontaneously so as to minimize any voltage-drop along the surface. This is because the lines end on charges, and like charges repel. When the metal forms an electric circuit such as a wire this movement involves a conversion of dielectric energy into

End view of wire

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reluctivities different from nonmagnetic materials. There is a complication
however, that the reluctivity of any portion of a magnetic circuit varies
with the ratio of flux to cross sectional area. Let this ratio be known
as flux density, $\mathcal{B}$, that is,

$$\mathcal{B} = \frac{\Phi}{A} \qquad \text{Kilomaxwells per square inch}$$

The variations in reluctivity can be expressed only graphically, and are
shown on the chart, page 87.

for wood, plastic, and most materials not shown on the chart the value
for reluctivity is 315 at any flux density, and no material is known for
which it is more than this (except titanium and a few others for which it is
slightly greater); hence there is no magnetic insulator. When a magnetic
circuit includes varying materials or nonuniform cross sections arranged
in series with each other (without abrupt change of section) the combined
reluctance may be obtained from

$$\mathcal{R}_o = \mathcal{R}_1 + \mathcal{R}_2 + \mathcal{R}_3 + \cdots$$

where $\mathcal{R}_o$ = reluctivity of the whole magnetic circuit, and $\mathcal{R}_1$, etc. =
reluctivity of separate parts of the circuit.

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and like charges repel. When the model forms
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involves a conversion of dielectric energy into

magnetic, with lines of magnetic flux interlinking the electric circuit. These magnetic lines at any point in the medium near the wire are perpendicular to the dielectric lines of flux at that point, and a flow of energy tends to take place through the medium surrounding the wire in a direction at right angles to both the dielectric and magnetic lines. Such a flow of energy constitutes what is commonly known as electricity, manifesting itself by heat liberated from the wire, or by a mechanical force tending to move the wire or iron objects near it.

The inverse of the effect just mentioned also occurs, namely that if the linkage of an electric circuit with magnetic lines of flux is changed, energy is required as by exerting a mechanical force to move a wire, and such energy is converted into a dielectric field between the sides of the electric circuit, which in turn causes current to flow in it. This effect is called electro-magnetic induction, and it is of much practical importance because commercial generation of electric power is largely by this means.

A charged body and a permanent magnet may lie motionless close together without influencing each other, but whenever a dielectric and magnetic field are changing with respect to each other there are definite mutual effects. For instance if a permanent magnet be brought near or
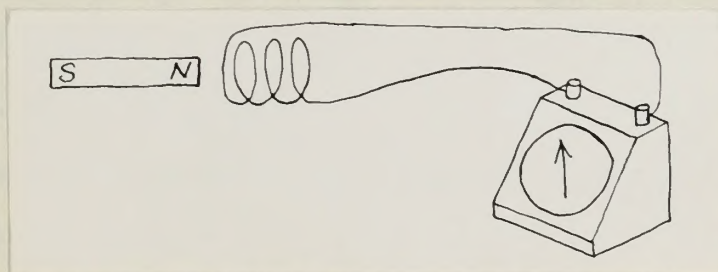
taken away from a coil of wire, with the circuit through the coil completed by connection to a galvanometer, the pointer will be deflected during the motion of the magnet, in one direction for approach and in the other

for removal.

Consider the circular ring shown on page 87 and let there be a wire loop as shown, connected to a separate circuit near a compass needle, and so placed that the magnetic lines of the circular ring interlink the turns of the loop. If the loop be suddenly withdrawn from the slot in the ring, so that its turns cut the magnetic lines, an electric charge will flow through the loop and move the compass needle. It is found experimentally that the value of this charge may be expressed

$$q = \frac{\Phi}{100,000\,R} \quad \text{coulombs}$$

where Φ = kilomaxwells of flux through the loop before it is withdrawn, and R = resistance of the loop circuit in ohms. (This is for a loop of one turn. For several turns the charge is increased in proportion to the number of turns.) The flux may be determined by the previous equation $\Phi = NI/\mathcal{R}$. Substituting algebraically in the relation

$$I = \frac{q}{t} \qquad \text{gives} \qquad I = \frac{\Phi}{100,000\,R\,t}$$

Then, since E = I R, it follows that

$$E = \frac{\Phi}{100,000\,t} \qquad \text{volts}$$

where t = time in seconds for the wire to cut Φ kilomaxwells of flux. This relation provides an essential numerical connection between values of magnetic quantities and of electrical quantities.

The so-called unipolar dynamo is a case where the induced voltage is uniform over intervals of time. The diagram shows such a dynamo designed so that the north and south pole surfaces are concentric cylinders between which there is an air gap so that a wire may be swept across radial lines

$$q = \frac{\Phi}{100,000\,R}$$ coulombs

$$I = \frac{q}{t} \qquad I = \frac{\Phi}{100,000\,R\,t}$$

$$E = \frac{\Phi}{100,000\,t}$$ volts

of flux. The ends of the wire are fastened to rings on which brushes bear,
to make connections with an external circuit. A design of this type gives
a continuous direct current and would be advantageous except that the
voltage is too low for most practical applications.

Brush

Wire revolving
with shaft

Drive
pulley

Field
magnet

Revolving
iron shaft
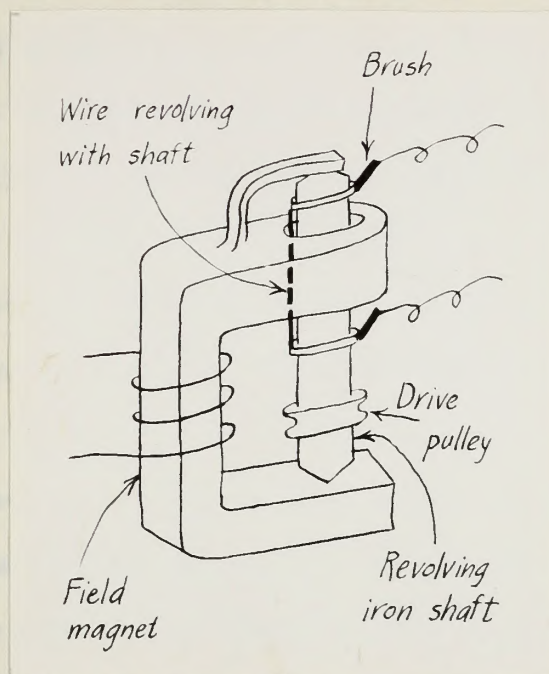
Principles--Direct Current Electricity.

The act of separating two dissimilar materials may cause them to become

    charged.

Charges are of two opposite kinds, designated positive and negative.

A dielectric field of energy surrounds a charged body. An unlike charge

    is attracted, or a like charge is repelled.

Charges move freely along conductors, but their motion is restricted by

    insulators.

Charges tend to move in the dielectric field through a drop in voltage,

    just as masses tend to move in the gravitational field through a drop

    in height.

A voltaic cell consists of two different metals in a solution of an acid,

    a base or a salt. When a wire is connected as a circuit outside the

    cell from one metal to the other, charges flow along the wire.

Current is the rate at which charge passes a given point in a circuit per

    second. The amount of current may be measured by the rate of deposit-

    ing metal in an electrolytic cell.

Energy is converted in various ways by current along a wire. Some energy

    is always converted into heat.

The voltage-drop between any two points in a circuit is the quotient of

    the rate of energy conversion in that segment of the circuit divided

    by the current.

The resistance between any two points in a circuit equals the quotient of

    the voltage-drop between them and the current.

The resistance of a wire depends upon its diameter, its length, and the

    kind of metal of which it is made.

The act of separating two dissimilar materials may cause them to become charged.

Charges are of two opposite kinds, designated positive and negative.

A dielectric field of energy surrounds a charged body. An unlike charge is attracted, or a like charge is repelled.

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A voltaic cell consists of two different metals in a solution of an acid, a base or a salt. When a wire is connected as a circuit outside the cell from one metal to the other, charges flow along the wire.

Current is the rate at which charge passes a given point in a circuit per second. The amount of current may be measured by the rate of depositing metal in an electrolytic cell.

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The voltage-drop between any two points in a circuit is the quotient of the rate of energy conversion in that segment of the circuit divided by the current.

The resistance between any two points in a circuit equals the quotient of the voltage-drop between them and the current.

The resistance of a wire depends upon its diameter, the length, and the kind of metal of which it is made.

The voltage-drop between any two points in a circuit connected by wires

    forming more than one path is the same irrespective of the path.

A magnetic field and current are two manifestations of the same phenomenon,

    namely motion of charges. A magnetic field of energy always sur-

    rounds a current-carrying wire.

A magnetic field may be represented by lines of flux forming closed loops.

    A north magnetic pole cannot exist independently of a south pole.

Iron and steel are magnetic but not most other materials. More lines of

    flux are set up in magnetic materials by a given current than in

    nonmagnetic materials. The reluctance of iron or steel is considerably

    less than that of most other materials.

The amount of magnetic flux interlinking an electric circuit is the

    quotient of the ampere-turns divided by the reluctance.

The reluctance of a given sample of iron varies with the flux density.

Current in a wire tends to twist a nearby magnet into a position parallel

    to the lines of flux.

Motion of a magnet so that its lines of flux cut a nearby wire induces a

    voltage-drop in the wire.

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forming more than one path is the same irrespective of the path.

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Current in a wire tends to twist a nearby magnet into a position parallel
to the lines of flux.

Motion of a magnet so that its lines of flux cut a nearby wire induces a
voltage-drop in the wire.

Test Direct Current Electricity

Mark in the right margin the letter corresponding to each item in the
    left column. Use each letter once and only once, and leave blanks
    after the two surplus words.

Used in storage batteries (A)	tungsten	( )
Used in dry cells (B)	lead	( )
Used for the filaments of lamp bulbs (C)	field	( )
Liquid conductor of electricity (D)	electron	( )
Found in the nucleus of an atom (E)	proton	( )
Negative unit of electricity (F)	chromium	( )
Behavior of positive charge with negative charge (G)	insulation	( )
	attraction	( )
Condition of stored energy between two oppositely	zinc	( )
charged bodies (H)	electrolyte	( )

* * * * * * * * *

If the statement is correct, write 'true' on the line at the right. If
    it is incorrect, write the term that must be substituted for the
    underlined term, to make the statement correct.

A glass rod rubbed with silk should attract another glass rod
    rubbed with silk.

The two leaves of a charged electroscope carry similar
    charges.

A metal plate connected to ground by a wire can never
    carry a charge.

Watts may be measured by the mass of metal deposited in
    an electrolytic cell per second.

In a parallel circuit the voltage is the same for all
    devices.

The amperes in all devices connected in series are the
    same.

Dry cells are connected in parallel to raise the voltage.

If a 5-ohm wire and a 10-ohm wire are connected in parallel
    across a steady voltage-drop, the 5-ohm wire will
    carry half as much current as the other.

Direct Current Electricity

Mark in the right margin the letter corresponding to each item in the left column. Use each letter once and only once, and leave blanks after the two surplus words.

( )   tungsten

( )   lead

( )   field

( )   electron

( )   proton

( )   chromium

( )   insulation

( )   attraction

( )   mica

( )   electrolyte

(A) Used in storage batteries

(B) Used in dry cells

(C) Used for the filaments of lamp bulbs

(D) Liquid conductor of electricity

(E) Found in the nucleus of an atom

(F) Negative unit of electricity

(G) Behavior of positive charge with negative charge

(H) Condition of stored energy between two oppositely charged bodies

* * * * * * * * *

If the statement is correct, write "true" on the line at the right. If it is inaccurate, write the term that must be substituted for the underlined term, to make the statement correct.

A glass rod rubbed with silk should attract another glass rod rubbed with silk.
_____

The two leaves of a charged electroscope carry similar charges.
_____

A metal plate connected to ground by a wire can never carry a charge.
_____

Watts may be measured by the mass of metal deposited in an electrolytic cell per second.
_____

In a parallel circuit, the voltage is the same for all devices.
_____

The sources in all devices connected in series are the same.
_____

Dry cells are connected in parallel to raise the voltage.
_____

If a 6-ohm wire and a 12-ohm wire are connected in parallel across a steady voltage-drop, the 6-ohm wire will carry half as much current as the other.
_____

Halving the diameter of a wire doubles its resistance. _____

For measuring wire diameters, the mil is 1/1000 of a
centimeter. _____

The resistance of a wire increases as the temperature rises. _____

Comparing a household flatiron rated 400 watts with a
percolator rated 250 watts, the percolator has the
lower resistance. _____

The presence of an electric current flowing along a
wire may be made known by a compass. _____

A magnetic field always interlinks a wire which is carrying
current. _____

When a conductor cuts across magnetic lines of flux, a
voltage-drop is induced. _____

The current induced in any one coil of the revolving
armature of a dynamo is an alternating current. _____

* * * * * *

Each statement is followed by various ways of completing it, only one
of which is correct. Mark x in front of the correct way.

A necessary condition for any motion of electrons from A to B is --
( ) absence of insulation between A and B ( ) presence of an
electrolyte between A and B ( ) difference of voltage between A
and B ( ) a magnetic field between A and B.

One purpose of a capacitor is to -- ( ) store dielectric energy ( ) neutra-
lize electric charges ( ) discharge a charged body.

A capacitor consists of -- ( ) two conductors joined together ( ) two
insulators joined together ( ) two conductors separated by an in-
sulator ( ) two insulators separated by a conductor.

A revolving glass plate machine is not an important commercial source of
electricity because -- ( ) it cannot produce large charges ( ) its
output will flow only through dielectrics ( ) it cannot produce a
steady flow ( ) it does not convert energy fast enough.

If a (negatively) charged vulcanite rod be brought toward a brass rod
lying on a paraffin block, the brass rod -- ( ) becomes negatively
charged at the near end ( ) becomes positively charged at the near
end ( ) becomes charged only if the far end be touched with the
finger ( ) retains opposite charges at its two ends after the

Halving the diameter of a wire doubles the resistance.

For commercial wire diameters, the mil is 1/1000 of an inch.

The resistance of a wire increases as the temperature rises.

Comparing a household flatiron rated 550 watts with a percolator rated 220 watts, the percolator has the lower resistance.

The presence of an electric current flowing along a wire may be made known by a compass.

A magnetic field always interlinks a wire which is carrying current.

When a conductor cuts across magnetic lines of flux, a voltage-drop is induced.

The current induced in any one coil of the revolving armature of a dynamo is an alternating current.

*   *   *   *   *   *   *   *   *

Each sentence is followed by various ways of completing it, only one of which is correct. Mark x in front of the correct way.

A necessary condition for any motion of electrons from A to E is — ( ) absence of insulation between A and B ( ) presence of an electric( )the between A and B ( ) difference of voltage between A and B ( ) a magnetic field between A and B.

The purpose of a capacitor is to — ( ) store dielectric energy ( ) neutralize electric charges ( ) discharge a charged body.

A capacitor consists of — ( ) two conductors joined together ( ) two insulators joined together ( ) two conductors separated by an insulator ( ) two insulators separated by a conductor.

A revolving glass plate machine is not an important commercial source of electricity because — ( ) it cannot produce large charges ( ) its output will flow only through a dielectric ( ) it cannot produce a steady flow ( ) it does not generate energy fast enough.

If a (negatively) charged vulcanite rod be brought toward a brass rod lying on a paraffin block, the brass rod ( ) becomes negatively charged at the near end and ( ) becomes positively charged at the near end ( ) becomes charged only if the rod be touched with the ( ) takes the opposite charge at the two ends after the

vulcanite rod is withdrawn.

Which one of the following prefixes means one-millionth -- ( ) kilo ( ) mega
( ) milli ( ) micro ( ) centi.

Of the following, who was born first -- ( ) Newton ( ) Rutherford ( ) Gal-
ileo ( ) Faraday.

A voltaic cell may be made using -- ( ) two pieces of copper in an acid
solution ( ) a rod of iron and a rod of aluminum dipping into
a salt solution ( ) a rod of copper and a rod of zinc dipping into
kerosene ( ) a copper wire with one end dipping into an acid and
the other into a salt solution.

The voltage between terminals of a voltaic cell depends mostly on --
( ) the chemical nature of the essential parts ( ) the quantity of
solution used ( ) the distance between the electrodes ( ) more
than any one of the foregoing items.

Of the following, a metal which is commercially refined by electrolysis
is -- ( ) mercury ( ) lead ( ) aluminum ( ) iron.

The electrolyte used in a dry cell is -- ( ) sulfuric acid ( ) carbon
( ) manganese dioxide ( ) ammonium chloride ( ) sodium chloride.

When current passes along a copper wire -- ( ) electrons exchange places
with protons ( ) electrons pass from atom to atom ( ) atoms move
from one end of the wire to the other ( ) electrons travel along
the wire at about the speed of light.

Direct current will not pass through-- ( ) graphite ( ) mercury ( ) an
acid solution ( ) a capacitor.

The common storage battery stores -- ( ) electricity ( ) heat ( ) lead
peroxide ( ) chemical energy.

If the resistance of a piece of wire is 12 ohms, the resistance in ohms
of another piece of the same metal and same length but of twice the
diameter is -- ( ) 3   ( ) 6   ( ) 24   ( ) 48.

The rate of heat production in a coil of nichrome wire with 100 volts across
its ends will be doubled if -- ( ) the coil is made of the same wire
but twice as long ( ) the coil is made of the same wire but half as
long ( ) the same coil is used but the voltage across its ends is
raised to 200.

In a given wire a current of one ampere liberates 3 calories per second. If
the current is increased to 2 amperes, the calories per second become --
( ) 3 ( ) 6   ( ) 9   ( ) 12.

If the voltage between two points in a circuit carrying 5 amperes is 100
volts, the power consumed between those points is -- ( ) 20 ohms

wulsanite rod is withdrawn.

Which one of the following prefixes means one-millionth -- ( ) kilo ( ) mega ( ) milli ( ) micro ( ) centi.

Of the following, who was born first -- ( ) Newton ( ) Rutherford ( ) Galileo ( ) Faraday.

A voltaic cell may be made using -- ( ) two pieces of copper in an acid solution ( ) a rod of iron and a rod of aluminum dipping into a salt solution ( ) a rod of copper and a rod of zinc dipping into kerosene ( ) a copper wire with one end dipping into an acid and the other into a salt solution.

The voltage between terminals of a voltaic cell depends mostly on -- ( ) the chemical nature of the chemical parts ( ) the quantity of solution used ( ) the distance between the electrodes ( ) more than any one of the foregoing items.

Of the following, a metal which is commercially refined by electrolysis is -- ( ) mercury ( ) lead ( ) aluminum ( ) iron.

The electrolyte used in a dry cell is -- ( ) sulfuric acid ( ) carbon ( ) manganese dioxide ( ) ammonium chloride ( ) sodium chloride.

When current passes along a copper wire -- ( ) electrons exchange places with protons ( ) electrons pass from atom to atom ( ) atoms move from one end of the wire to the other ( ) electrons travel along the wire at about the speed of light.

Direct current will not pass through-- ( ) graphite ( ) mercury ( ) an acid solution ( ) a capacitor.

The common storage battery stores -- ( ) slag right(?) ( ) heat ( ) lead peroxide ( ) chemical energy.

If the resistance of a piece of wire is 12 ohms, the resistance in ohms of another piece of the same metal and same length but of twice the diameter is -- ( ) 3 ( ) 6 ( ) 24 ( ) 48.

The rate of heat production in a coil of nichrome wire with 100 volts across its ends will be doubled if -- ( ) the coil is made of the same wire but twice as long ( ) the coil is made of the same wire but half as long ( ) the same coil is used but the voltage across its ends is raised to 200.

In a given wire a current of one ampere liberates 3 calories per second. If the current is increased to 2 amperes, the calories per second become -- ( ) 3 ( ) 6 ( ) 9 ( ) 12.

If the voltage between two points in a circuit carrying 5 amperes is 100 volts, the power consumed between those points is -- ( ) 20 ohms

( ) 20 watts   ( ) 500 watts   ( ) 500 kilowatt-hours.

The man who discovered the law connecting electric voltage, current and resistance was -- ( ) Franklin ( ) Faraday ( ) Ohm ( ) Oersted.

When measuring resistance with a slide wire Wheatstone bridge -- ( ) no current is drawn from the battery when the slider is in the correct position ( ) No current passes through the galvanometer when the slider is in the correct position ( ) The ohms in three resistances must be known ( ) The ohms in one meter of the slide wire must be known.

A unit of power is the -- ( ) volt ( ) joule per second ( ) ampere ( ) ampere-second.

A watt-hour is a unit of -- ( ) power ( ) energy ( ) charge ( ) field intensity.

Malleable iron rather than tempered steel is used for the cores of electromagnets because the iron -- ( ) is cheaper ( ) can be forged and bent easily ( ) loses its magnetism when the circuit is broken ( ) contains less carbon than steel.

The iron in a bar is certainly proved to be magnetized if one end appears to -- ( ) attract a pith ball ( ) repel a pith ball ( ) attract one pole of a compass needle ( ) repel one pole of a compass needle.

A commercial device depending for its operation on the magnetic effect of an electric current is the -- ( ) storage battery ( ) toaster ( ) electric bell ( ) flashlight.

Any usual form of galvanometer -- ( ) consists of a fixed coil and a moving permanent magnet ( ) consists of a moving coil and a fixed permanent magnet ( ) essentially indicates watts ( ) may readily be used to indicate the charge on a Leyden jar.

A galvanometer could be used as a voltmeter by -- ( ) using a high resistance shunt across it ( ) putting a high resistance in series with it ( ) putting a low resistance in series with it ( ) using a stronger magnet in it.

The strength of an electromagnet depends chiefly on -- ( ) voltage and size of wire ( ) resistance and size of the core ( ) voltage and the material of the core ( ) amperage and number of turns of wire.

SUMMARY

Considering the importance of the scientific method, the teaching of it should be a primary, not a secondary aim. Of all sciences, physics in particular gives an opportunity for selecting hypotheses, observing phenomena, assembling data, and testing results. Yet it is well nigh impossible to find an elementary physics textbook which suggests this method for introducing various laws of mechanics and electricity. Far too often the attempt has been made to teach physics by stating principles as coming from authority. The difficulty is that much of science has been taught by repeating the methods of those who have preceded. In this paper it has been shown that certain of the more perplexing topics can be treated at the preparatory school level in a manner corresponding to the scientific method.

For many years the exposition of physics in secondary school textbooks has been set in an excessively traditional form. Authorities have been cited who deplore this situation, and express the need for new approaches. It should be possible to obtain them, for modern mathematics and physics indicate that there are many approaches and many solutions to the understanding of concepts. When alternative means for comprehending a difficult concept, or group of concepts, can be provided, there is a far better chance of eventually reaching those young students who have not comprehended the first time.

To attack the problem, various applications of the principles of psychology of learning to physics have been given in the first portion of this paper. It has been suggested that many teachers do not realize the large amount of conditioning to symbols and units that is expected of the

student. Becoming conditioned to physics formulas has been compared with

Kingsley's illustration of becoming conditioned to the word 'apple'.[1]

As a further attack on the problem, several poor practices in the

current teaching of physics have been examined, and difficulties for the

learner have been analyzed. When a textbook gives a treatment which is

misleading, a student may find after he reaches college that he has not

really learned some topic correctly the first time, and it becomes trebly

troublesome to unlearn. Among the difficulties for the pupil, it is to be

especially noted that the metric set of standards of measurement has been

advocated and used for the past fifty years. It is possible that in all

this time there has been no advantage, and a complication has been intro-

duced at a level where simplicity is desirable. Gaining familiarity with the

metric system may be made an 'optional related activity' for those who are

trying for a mark of better than B +.

Three chapters of an auxiliary text for pupils have been prepared to

incorporate:

        --clear exposition
        --a combination of logical and psychological organization
        --restriction to the use of familiar units of measure
        --new ways of thinking about important concepts

The presentation follows a possible scheme of pupil activities, even lead-

ing by the experiential route to the essential mechanical relation

$F = m\,a$. There is no evidence that this latter has ever been done before.

Each chapter is followed by a list of principles, and by an objective test

which may be used to measure pupil achievement. The three chapters are

intended to be reproduced by mimeograph, or otherwise, for the use of grade

XII students in preparatory schools.

[1] Howard L. Kingsley. The Nature and Conditions of Learning, page 269.
        New York: Prentice-Hall, Incorporated, 1946.

It should be possible to carry the idea of this paper further by the preparation of definite units of learning, that is, delimitations, core activities and optional related activities in the sense advocated by Billett.[1] Moreover the work may be expanded into other functional areas in physics, such as calorimetry, optics and alternating currents. Any teacher who attempts to select desirable learning products in any of these areas, and organize subject matter psychologically so that his pupils attain them, will find that he benefits immeasurably. The creation of a series of logical steps in developing concepts is the same process through which the original users of these concepts went. The satisfaction in doing this is one which is too infrequently capable of realization.

[1] Op. cit., chapter XVII.

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